Emergency Shelters for Humanitarian Aid after Natural Disasters

Dissertation

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by

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*) Either the German or the Italian form of the title may be used.

Abstract

Every year hundreds of thousands of people become homeless due to natural disasters and are consequently in need of temporary accommodation until they can return to their reconstructed homes. Immediately after a disaster this temporary accommodation is provided by emergency shelters. In developing countries these emergency shelters are often family tents which, especially in cold climate disaster regions, however do not provide adequate shelter. An example of this is the Pakistan earthquake in 2005 where no appropriate winterised tents were available and thermal comfort could not be gained, given the extremely cold winter conditions. Aiming to improve this situation the present work researches in detail the possibilities of a floor and roof insulation as well as the required bedding as parts of a winterisation kit.

The very specific problem of tent winterisation fits in the much broarder overall topic of this work, i.e. the risk management of post-disaster homelessness. Using the data of past disasters, the spread of homelessness for different disaster types and regions was analysed. Furthermore, a risk index for homelessness due to earthquakes was developed and the significant influence of the socio-economic boundary conditions on the post-disaster sheltering situation was identified.

In its second part the work responds to the pressing need for the winterisation of family tents by presenting a number of different options for a floor insulation. The use of infrared reflective materials for the floor as well as for the roof insulation proved to be very promising. Finally, due to the lack of any guidance on the required disaster relief bedding in cold regions, a model for the determination of thermal comfort during sleeping was developed. Concluding, the developed winterisation kit facilitates better living conditions not only immediately after the disaster but as well in the long term, as adequate emergency shelters offer more time for a better reconstruction.

Zusammenfassung

Jedes Jahr werden Hunderttausende Menschen durch Naturkatastrophen obdachlos. In der Folge benötigen sie eine temporäre Unterkunft bis sie in ihre wiederaufgebauten Häuser zurückkehren können. In der Anfangsphase werden daher zunächst Notunterkünfte zur Verfügung gestellt. In Entwicklungsländern sind dies häufig Zelte, die jedoch keinen ausreichenden Schutz vor Kälte bieten. Dies wurde einmal mehr durch das Pakistan Erdbeben von 2005 unterstrichen, bei dem keine wintertauglichen Zelte zur Verfügung standen. Daher untersucht die vorliegende Arbeit unterschiedliche Optionen für die Boden- und Dachisolation, die schließlich in einem sogenannten "winterisation kit" für Familienzelte zusammengefasst werden.

Neben dem winterisation kit beschäftigt sich die Arbeit im ersten Teil mit den allgemeineren Aspekten des Risikomanagements von Obdachlosigkeit nach Naturkatastrophen, welches das Gesamtthema der Arbeit ist. Basierend auf den Daten vergangener Katastrophen wird die Verteilung der Obdachlosigkeit über verschiedene Katastrophenarten und Regionen ausgewertet. Ein Risikoindex für Erdbeben wird entwickelt sowie der Einfluss sozioökonomischer Randbedingungen auf die Unterkunftssituation nach Katastrophen nachgewiesen.

Ausgehend von dem dringenden Bedarf an wintertauglichen Zelten werden im zweiten Teil der Arbeit verschiedene Varianten einer Bodenisolierung präsentiert. Besonders die Verwendung infrarot reflektierender Materialien sowohl für die Boden- als auch für die Dachisolierung ist viel versprechend. Als Reaktion auf das Fehlen jedweder Standards für den Einsatz von Bettzeug in kalten Klimata wurde ein Model entwickelt, welches den thermischen Komfort beim Schlafen sicherstellt.

Zusammenfassend resultiert das vorgestellte winterisation kit für Notunterkunftszelte in einer Verbesserung der Lebensbedingungen nicht nur unmittelbar nach der Katastrophe sondern auch auf lange Sicht, da adäquate Notunterkünfte mehr Zeit für einen besseren Wiederaufbau bieten.

To my husband

Acknowledgements

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Contents

Abbreviations

ALNAP	Active Learning Network for Accountability and Performance in Humanitarian Action
CGI	Corrugated Galvanised Iron
Clo	unit for measuring clothing's insulation; 1 $Clo = 0.155\ m^2K/W$
CRED	Centre for Research on the Epidemiology of Disasters
DAP	Draught Animal Power
DPA	Deutsche Presse Agentur
EM-DAT	Emergency Disasters Data Base
EPS	Expanded Polystyrene; also known under the trade name Styropor
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FEMA	Federal Emergency Management Agency
FRC	Federal Relief Commission for relief after Pakistan earthquake, October 2005
GDP	Gross Domestic Product
HD	Human Development
HDI	Human Development Index
HDPE	High Density Polyethylene
homel.	homeless
HSNDS	H. Sheikh Noor-ud-Din Sons Private Limited; tent manufacturer and supplier of emergency relief items
ICRC	International Committee of the Red Cross
IFRC	International Federation of Red Cross and Red Crescent Societies
IOM	International Organization for Migration
IR	Infrared
ISDR	International Strategy for Disaster Reduction
LDPE	Low Density Polyethylene
LST	Land Surface Temperature
LWET	Light Weight Emergency Tent
LWWFT	Light Weight Winterized Family Tent
LWWT	Light Weight Winterized Tent

mio.	million
MM	Modified Mercalli scale
MSF	Médecins Sans Frontières
NATHAN	NATural Hazards Assessment Network
NFI	Non-Food Item
NGO	Non-Governmental Organisation
no.	number
OCHA	UN Office for the Coordination of Humanitarian Affairs
OFDA	Office of U.S. Foreign Disaster Assistance
PD	Percentage of Dissatisfied
PE	Polyethylene
PP	Polypropylene
PPD	Percentage of People Dissatisfied
PUR	Polyurethane
refl.	reflective
rel.	relative
res.	resistance
RM	Risk Management
SDC/HA	Swiss Agency for Development and Cooperation/Humanitarian Aid
th.	thermal
THW	Technisches Hilfswerk
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organisation for Applied Scientific Research)
UN	United Nations
UNDP	United Nations Development Programme
UNDP/IASPO	UNDP's Inter-Agency Procurement Service Office
UNDRO	United Nations Disaster Relief Office; now: United Nations Office for the Coordination of Humanitarian Affairs (UN/OCHA)
UNHCR	United Nations High Commissioner for Refugees
UNICEF	United Nations International Children's Emergency Fund
USAID	United States Agency for International Development
WFP	United Nations World Food Programme
XPS	Extruded Polystyrene; also known under the trade name Styrodur

Chapter 1

Introduction

Every year hundreds of thousands of people become homeless due to natural disasters. Floods, earthquakes, wind storms and many other disaster types damage or destroy their homes so that they need temporary accommodation until the completion of reconstruction allows them to return to their rebuild homes. While the situation in industrialised countries is generally characterised by the availability of appropriate temporary accommodation (e.g. hotels, schools, relatives) and a fast reconstruction, the situation in developing countries is much different. In many cases the only available temporary accommodation are tents in which the affected often live for years until they can return to rebuild homes. Especially in cold climate regions this situation leads to very poor sheltering conditions, as the mostly uninsulated tents cannot provide the essential thermal comfort. Apart from low internal air temperatures the thermal situation is negatively affected by draughts and condensation while tent collapses under snow loading and flooding of tented camps further worsen the living conditions. Unfortunately, the Pakistan earthquake of October 2005 with its 3.5 million homeless and extremely cold winters provided again an example of these poor conditions. Given Maslow's hierarchy of needs which identifies shelter as a basic life need (see Figure 1.1), the importance of appropriate humanitarian aid on shelter in the aftermath of natural disasters is therefore apparent[1].

The present work will deal with the highlighted need for post-disaster shelter, analyzing how it is provoked by natural disasters and how the required shelter aid can be improved. Generally, humanitarian aid on shelter is given in three phases starting off immediately after the disaster with the provision of emergency shelters (see Figure 1.2). For these a wide variety of options exists, ranging from hotels, host families, public buildings up to family tents. Ideally the time spent in emergency shelters is short, but in many cases it may last up to years. This first shelter is substituted by transitional shelters which are usually more durable and intended for a period of use of a couple of month or even years. Often it can be observed that this phase is omitted and that an immediate transition from emergency shelters to reconstructed homes is facilitated.

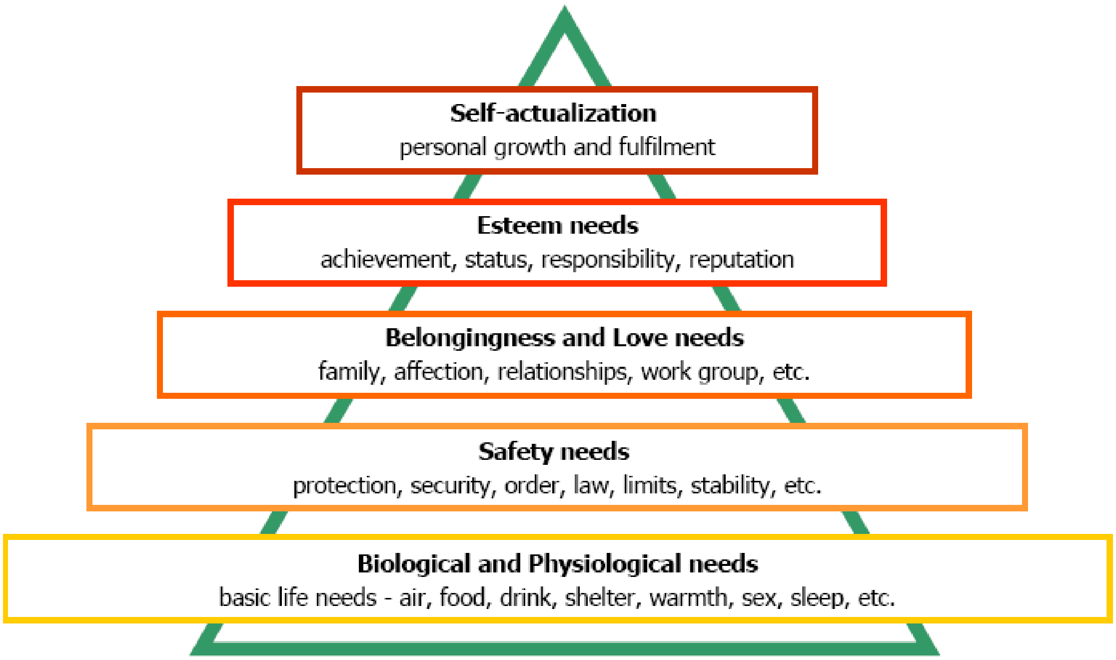


Figure 1.1: Maslow's hierarchy of needs [Chapman, 2008]

Finally, the reconstructed homes represent a long-term solution and the last phase of shelter aid. While the given distinction of three phases of shelter aid is the most common one and will be used subsequently in this work, it has to be noted that also other distinctions, like a four phase one (emergency shelters, temporary shelters, temporary housing and permanent housing) might be found[2]. Furthermore, in some circumstances the term transitional shelter is substituted by temporary shelter.

Out of the three types of shelter, this work will focus on those provided immediately after the disaster, i.e. the emergency shelters. As already indicated above, past disasters, and in special the situation of millions living in unsuitable tents after the Pakistan earthquake, have shown repeatedly that no appropriately winterised tents are available. Motivated by the necessity of improvements the major scope of the present work is to research in detail the possibilities of a winterisation kit for emergency shelter tents. By insulating standard relief tents it is aimed to provide thermal comfort and therewith appropriate shelters to the affected. Consequently, with no pressing shelter need created by insufficient emergency shelters, more time for a better reconstruction and the integration of disaster risk reduction methods is available. Therefore, improving winterised tents does not only mean to raise the preparedness for the disaster case but to offer as well a chance for 'building back better', the frequently addressed principle.

This research on cold climate emergency shelters is an integral part of the risk management of homelessness due to natural disasters which is the much boarder, overall

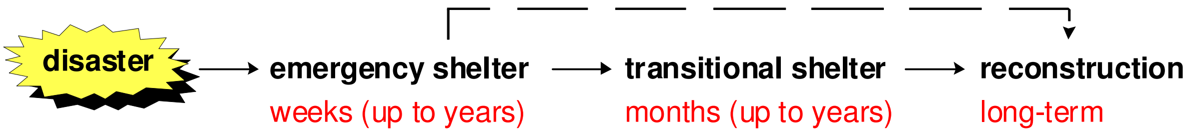


Figure 1.2: Three phases of post-disaster shelter aid

topic of this work. It shall be noted, that in the here discussed context the subsequently used term homelessness refers exclusively to persons which have lost their home due to a natural disaster even though it can be found in many other contexts. Risk management of homelessness means to deal with the risk of becoming homeless as a natural hazard acts upon exposed houses with a certain vulnerability. The objective of the risk management process is to analyse the risk and to develop appropriate measures to reduce it. To illustrate how this objective is met, in the following the structure of the present work will be discussed. In parallel to the description it shall be referred to Figure 1.3 which additionally provides a graphical scheme.

To raise the topic of the present work, the introduction discusses at a very general level the risk of homelessness which is created by the consilience of natural hazard, exposure and vulnerability, each represented by a circle at the top of Figure 1.3. Starting from this, in Chapter 2 a risk management process for homelessness due to natural disasters will be developed, upon which in the following the entire work will be based. It represents the very general definition of the topic of which, with the progress of the work, more and more detailed aspects will be dealt with, until at the end of the work the view will be widened again towards the general conclusion. Graphically this process is indicated by the degree of generality on the left hand side of Figure 1.3. The definition of the risk management process is followed by a risk analysis that investigates at a very general level which natural disasters have generated in the past homelessness and where (Chapter 2: Risk management process and risk analysis). More specifically, the question is raised which type of emergency shelter (e.g. hotel, school, tent) will be available depending on the encountered vulnerability (Chapter 3: Impact of vulnerability on sheltering options). Focusing on tents as emergency shelters it is discussed which basic shelter needs have to be satisfied in general, and how they are met in particular by winterised tents in the aftermath of disasters in cold climate regions (Chapter 4: Shelter needs). Referring to Figure 1.3 this is indicated by a tented camp under winter conditions. Continuing with the research on winterised tents, the perspective is shifted from the actual situation after the Pakistan earthquake towards the investigation of the availability of tents and non-food items for disaster relief. Additionally, it is analysed if a transfer of knowledge from tents used in other cold climate contexts such as nomad tents can be exploited (Chapter 5: Tent types). Combining the results of Chapter 4 and 5 it has to be concluded that in general a lack of appropriate winterisation and in special of a sufficient floor insulation exists. Therefore, at the most specific point of the

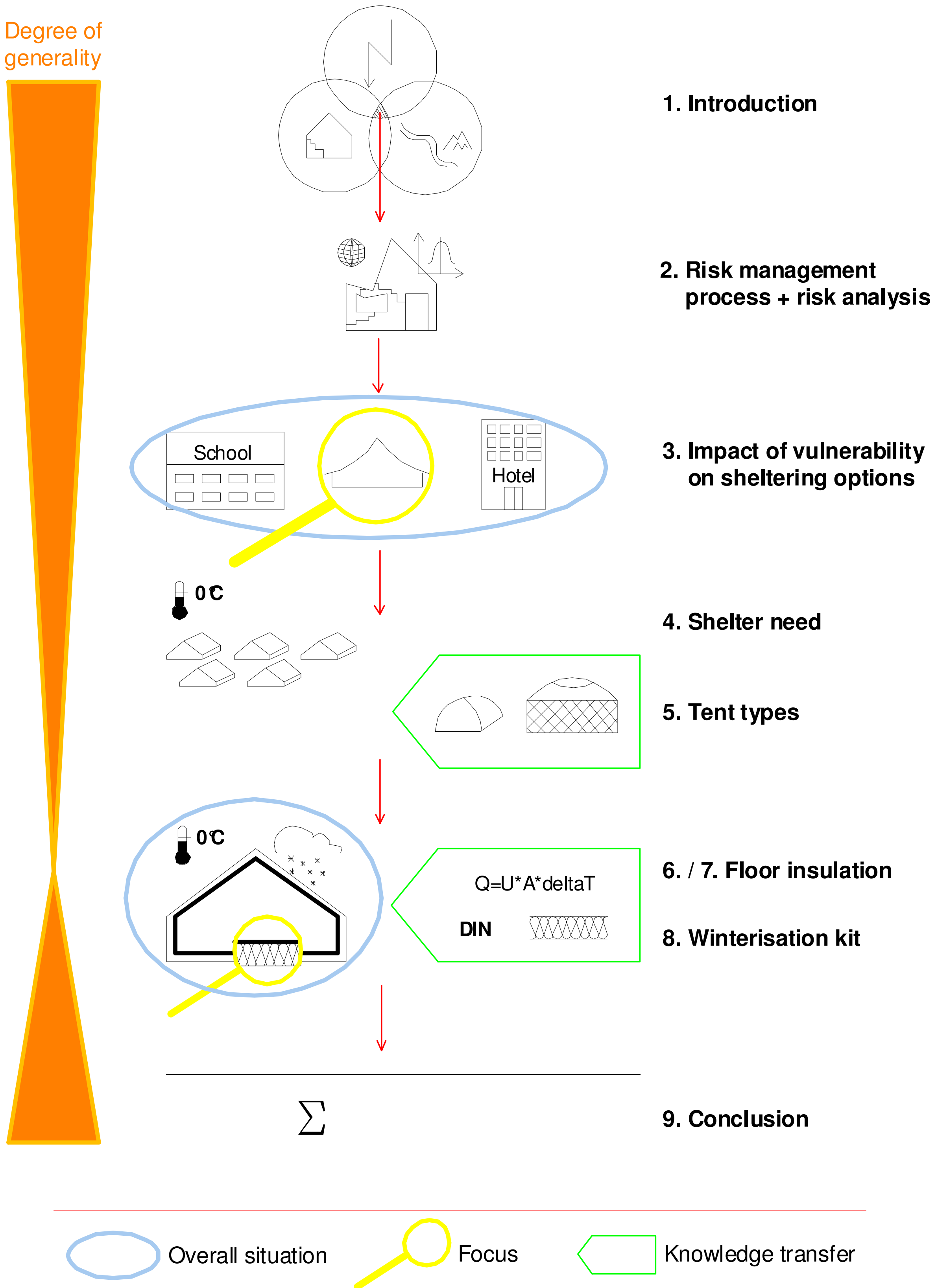


Figure 1.3: Graphical scheme of overall structure

work the very concrete element of a floor insulation is developed (Chapter 6/7: Floor insulation). This research is supported by a transfer of knowledge from other areas as thermodynamical analyses, building codes and building materials. Finally, the view is widened from this very specific object to an entire winterisation kit which for example includes bedding and a roof insulation (Chapter 8: Winterisation kit). Finally, a general perspective upon all obtained results will be given (Chapter 9: Conclusion).

Notes

[1]Maslow (1954)
[2]Nigg (2004), p. 119

Chapter 2

Risk Management and Analysis of Homelessness

2.1 Risk Management of Homelessness

2.1.1 Introduction

As the topic of this work are emergency shelters for humanitarian aid purposes it seems useful to understand the processes which lead to the need of emergency shelters and to get an overall understanding of their role within the risk management process. Emergency shelters become necessary in disaster situations with a large number of homeless. To develop improved emergency shelters means a raised preparedness for the disaster case and better living circumstances for the homeless after the disaster. Hence, they contribute to the overall process of risk management of homelessness. To understand not only at which point emergency shelters enter the stage in a post-disaster situation but to gain as well an insight in the overall sheltering situation and process, hereafter it will be dealt in detail with the risk management of homelessness. For this purpose, based on the risk management concept of Plate and a concept for risk mitigation of potential flooding areas in Schleswig-Holstein[1], a concept of an integrated risk management of homelessness was developed[2]. The risk management process is split in a pre-disaster and a post-disaster process which will be presented separately in the subsequent chapters. Finally both will be integrated in the overall risk management spiral which accounts for the progression of time.

2.1.2 Pre-disaster Risk Management

Figure 2.1 shows the pre-disaster risk management process. Its three major steps of risk analysis, risk evaluation and risk mitigation refer to the usual risk management procedure. As the focus of this work is on humanitarian aid in the following all other

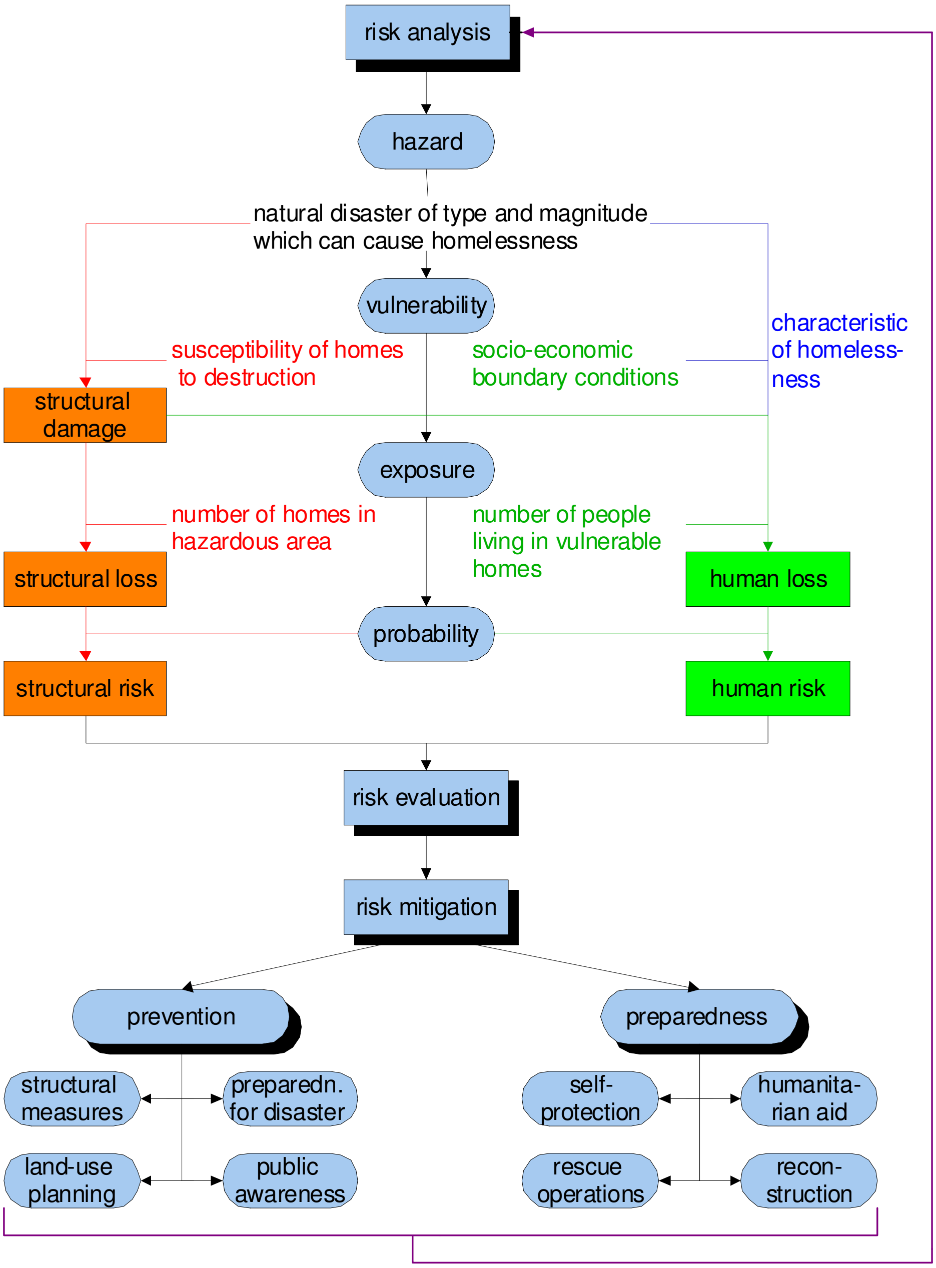


Figure 2.1: Pre-disaster risk management process

components will only be mentioned to give an overview of the whole risk management process of homelessness but will not be dealt with in further detail.

The risk analysis is based on the risk definition of Augusti, Borri and Niemann[3] who define:

$$RISK = HAZARD \cdot EXPOSURE \cdot VULNERABILITY$$

The distinction of three factors (hazard, exposure and vulnerability) instead of using only hazard and vulnerability, as can be often seen in literature, was made as it fits very well the purpose of analysing the risk of homelessness[4]. In order to calculate the risk it can be accounted for the implied probability in two ways: either by including it in each of the three factors of the risk equation or by using the three factors to calculate in an intermediate step the potential damage and loss and by finally multiplying this damage and loss with its probability[5]. Here the last-mentioned approach will be adopted as it was considered important not only to obtain the risk but as well the actual number of damaged homes and victims represented by the intermediate result of damage and loss.

Subsequently the meaning of the three factors of the risk equation and thereby the overall pre-disaster risk management process shall be discussed in more detail. Hazard refers to a natural disaster event of such type and magnitude that it can cause homelessness. It is the outer impact which affects some area with built structures and humans living within them. Although the impact of the natural disaster is not restricted on built structures and humans living within them, subsequently only these two factors shall be regarded as they are the defining factors for homelessness. In the following it shall be distinguished between the impact on structures and humans which is represented by the division of the diagram in a left (structural) and right (human) side.

Both structures and humans have a certain vulnerability to the impact of the disaster. Depending on the susceptibility of homes to the influence of natural disasters structural damage occurs. Introducing the factor exposure the structural damage can be transformed into losses. On the structural side exposure can be understood as the number of homes in the hazardous area. The human exposure is the number of people living in vulnerable homes. The structural damage together with the human exposure forms the human loss. This consists of death, injured and homeless which are evoked by the collapse or partial damage of their home. These human losses are secondary losses as they are generated by the structural damage and not by the natural hazard in the first place. That is why the concept considers vulnerability prior to exposure in order to show the sequence of structural damage and resulting human loss. However, with regard to deaths and injuries direct human losses due to the impact of the natural disaster e.g. the drowning in a flooding river might be possible as well. Due to the focus on homelessness the chosen process does not consider these direct human losses.

To account for the different forms of homelessness the contribution of human vulnerability is very important. Depending on the social-economic boundary conditions people have different options for temporary accommodation and the duration in these will vary largely. Chapter 3 will focus in more detail on the importance of human vulnerability for the characteristics of homelessness. Finally, the losses can be transformed into risk taking the probability into account. After obtaining the human and structural risk a risk evaluation can be carried out. Both risk analysis and risk evaluation will be dealt with in the subsequent chapters.

In the pre-disaster risk management process the risk evaluation can result in the necessity of risk mitigation measures which can be subdivided in prevention and preparedness. Both measures try to minimize the negative impact of a potential disaster. Whereas prevention aims to reduce the direct impact of the disaster, preparedness tries to alleviate the negative consequences of the occurred destruction. Most of the preventive measures aim to reduce the structural damage respectively (resp.) loss and thereby to minimize the number of homeless people. In contrast to this preparedness has only little influence on the number of homeless itself but tries to optimize the actions taken shortly before or immediately after the disaster in order to reduce the suffering of the homeless. Subsequent the meaning of the individual preventive and preparing measures will be explained.

PREVENTION

Structural Measures reduce the susceptibility of homes to the disaster impact.

Land-use Planning targets a reduction of exposure by minimising the settlement in hazardous areas.

Preparedness for the Disaster tries to reduce the losses by installing early warning systems, introducing disaster management plans and enabling the readiness for duty of civil protection.

Public awareness is an important tool to make the people understand the risks and thereby convince them not to settle in hazardous areas, build disaster resistant homes, insure their homes etc.

PREPAREDNESS

Self Protection focuses on the sensitive action of the individual which needs to be informed about possible disaster scenarios and a sensible behaviour under these circumstances.

Rescue Operations stand for the evacuation and rescue of people and assets out of the hazardous area. It comprises as well the rescue of dead and injured.

Humanitarian Aid helps the affected immediately after the disaster. It includes health care, nutrition, water and sanitation and emergency shelter.

Reconstruction means the repair or construction of infrastructure and buildings, the rebuilding of livelihoods etc.

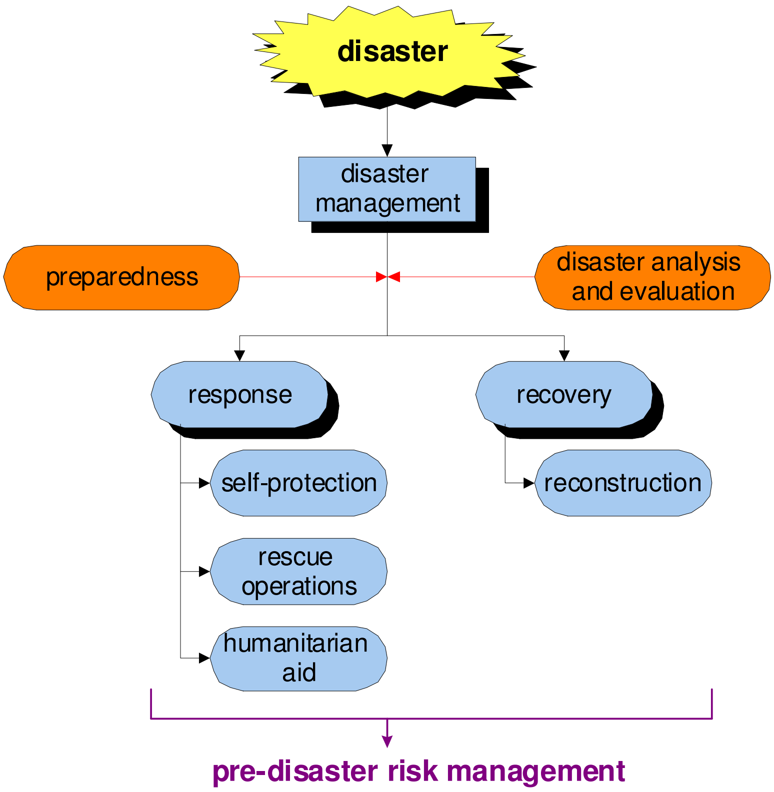


Figure 2.2: Post-disaster risk management process

2.1.3 Post-disaster Risk Management

In the case of a disaster the pre-disaster risk management cycle is interrupted by the process of post-disaster risk management of homelessness (see Figure 2.2). Immediately after the disaster the disaster management starts conducting the actions which were optimized in the preparing process before the disaster. An adaption of these actions to the given disaster situation becomes possible by a disaster analysis and evaluation which try to meet the needs as good as possible. Although in the event of a disaster a clear disaster analysis and evaluation is a difficult task it plays, together with the previously reached level of preparedness, a major role for the success of the relief and reconstruction efforts. The disaster management can be split in response and recovery. The response starts shortly before or immediately after the disaster and features a relatively short period. Recovery initiates as soon as possible after the disaster and can last for months, years or even decades. Finally, response and recovery are followed by a new cycle of pre-disaster risk management.

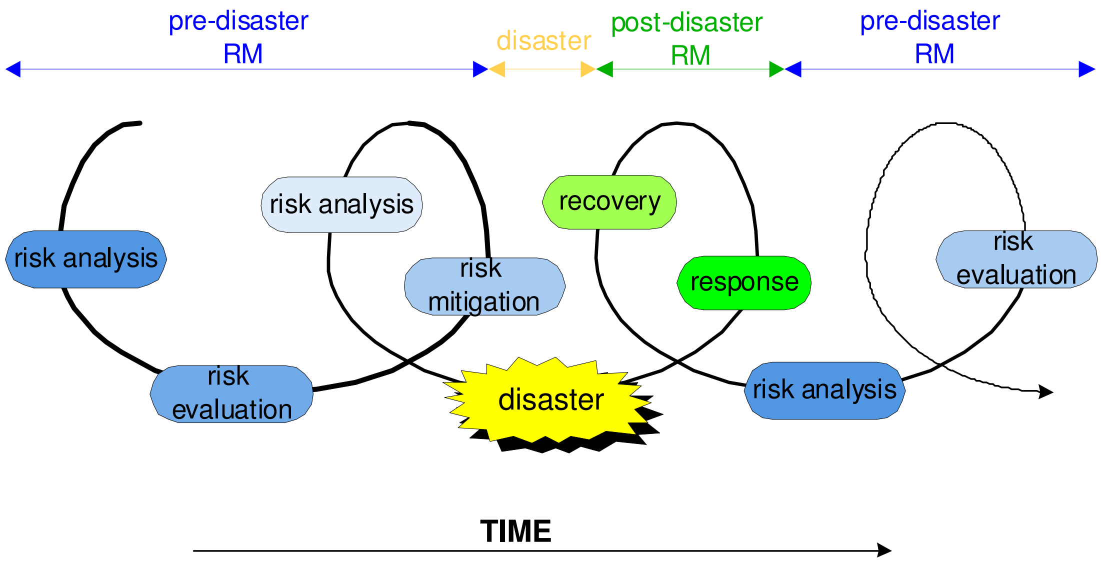


Figure 2.3: Spiral of risk management (RM) process over time

2.1.4 Risk Management Process over Time

Figure 2.3 shows the risk management process over the progression of time with the pre-disaster process being interrupted by a disaster and the consequent post-disaster process before the pre-disaster one starts again. During the preparing and preventive measures of the pre-disaster process as well as during the response and recovery of the post-disaster process the situation in the regarded area is changing. This necessitates a new risk analysis starting once again the pre-disaster process. However, although the process returns to its initial point, it does not start off from the same setting but considers a different, hopefully better one. Therefore, the gained process can be understood as a spiral of a development over time as more and more cycles are carried out.

2.2 Risk Analysis of Homelessness

Being an essential part of the risk management process the risk analysis of homelessness can be used to understand the complex processes and mechanisms which trigger homelessness after natural disasters. Pointing out the characteristics of homelessness in different disaster scenarios, it allows to derive the corresponding needs of the homeless. These needs then form the essential base for the development of appropriate and adapted emergency shelters.

For the purpose of the risk analysis historical data was evaluated and the results will be presented in the following chapters. Starting with the very general question which natural disasters generate homeless in which quantity the presented results will subsequently become more and more specific as the size of the regarded area diminishes (from continental regions towards countries).

2.2.1 Homelessness Generation

First of all it seems useful to identify the types of disaster which provoke homelessness. Referring to the trigger, the general term disaster can be split up in the three subgroups natural, technological and social[6]. Enhancing the disaster categories introduced by EM-DAT (Emergency Disasters Data Base) and ISDR (International Strategy for Disaster Reduction), Figure 2.4 shows a further subdivision of the three subgroups into specific disasters[7].

It has to be noted that the given distinction into natural, technological and social disasters is a simplification made for the purpose of categorisation. In reality, however, most disasters are such complex events that they cannot be purely natural, technological or social. Often it exists more than one trigger and in most cases the contribution of man cannot be neglected. Its contribution to the disaster event shall hereafter be termed man-made in order to distinguish it from the subgroup of social disasters which refers to different triggers. All disasters are to a certain degree man-made whereas only some can be classified by their main-trigger as social disasters[8]. An example for the contribution of man can be the natural event of a slide: although the final event of the slide is clearly a natural process, in the first place it might be triggered by man-made conditions such as deforestation, soil erosion etc. In the same way famine might be man-made by mismanagement but the underlying cause can be the natural event of a drought due to which the mismanagement became crucial. Wisner states that a natural disaster event can vary from being nearly completely natural to nearly completely man-made[9].

Beside the trigger which refers to the term hazard in the risk equation given in Chapter 2.1.2 the natural or man-made setting of the event plays a major role. This setting is represented in the risk equation by the factors exposure and vulnerability which – beside the trigger (hazard) – contribute largely to the impact of a disaster. An example of this contribution might be an earthquake of Richter scale 6.0 which is an intense natural event. But it only becomes a disaster if the man-made setting is vulnerable to earthquakes, e.g. houses are not earthquake resistant. The flooding of a river only provokes a disaster due to a large exposure, e.g. many people living in its flooding area. The previous two examples show clearly that not only the hazard (trigger) but also the vulnerability and exposure contribute to the impact of a disaster which is in correspondence with the three factors of the risk equation as given in Chapter 2.1.2. The before seen importance of vulnerability and exposure, which are mainly man-made factors, underline that, even though this work will focus on natural disasters, the man-made contribution to the events can and shall not be neglected. The importance of the man-made socio-economic boundary conditions that firstly influence the vulnerability

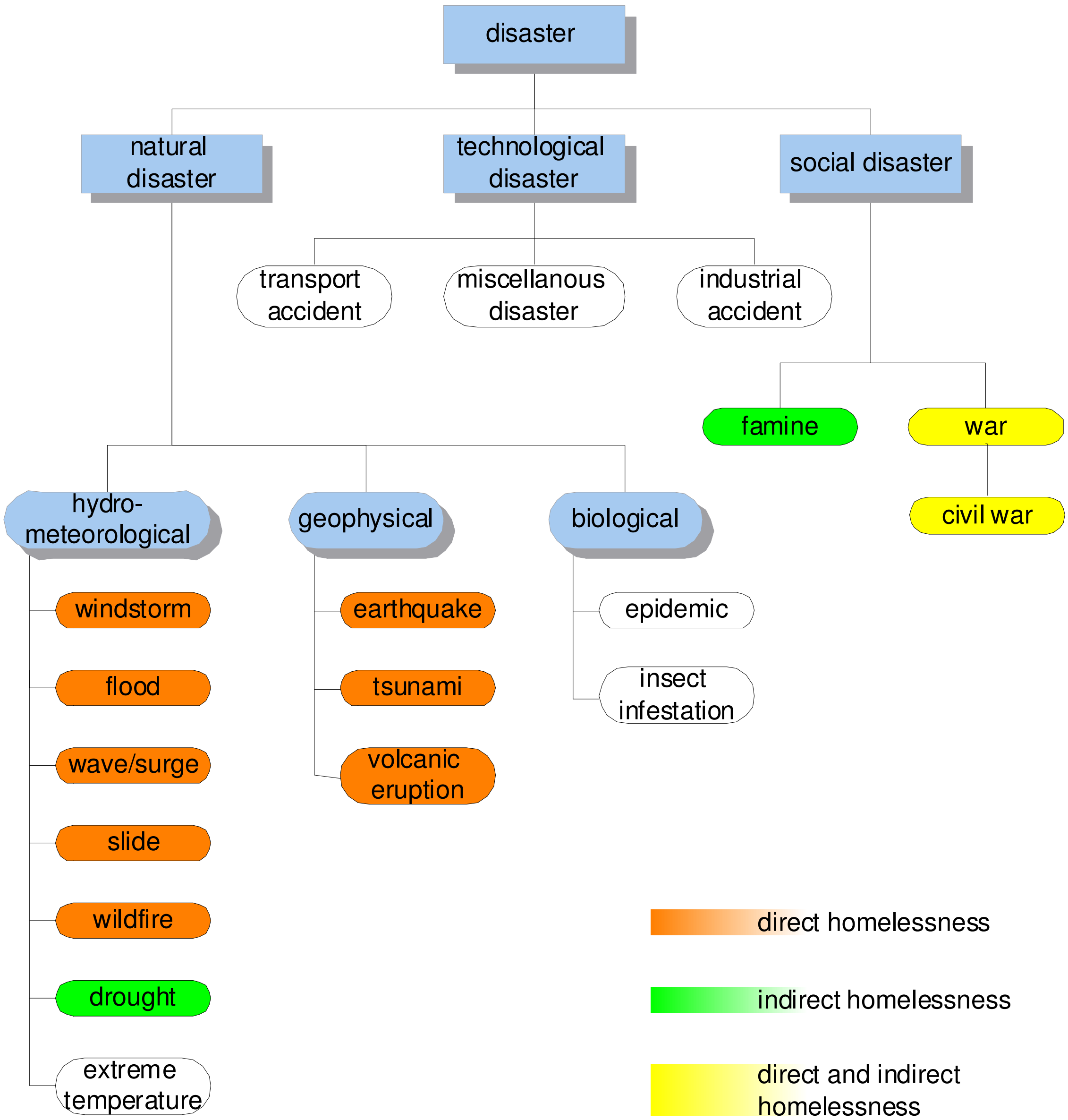


Figure 2.4: Disaster types and their creation of homelessness

and secondly the sheltering situation after the disaster will be discussed in detail in Chapter 3. Furthermore, it has to be noted that, although the trigger of events and hence their classification can be different, its disaster scenario might be very similar and therefore a common analysis can be useful. An example is the technological disaster of a dam collapse which will result in downstream flooding. With respect to the generation of homelessness this scenario is similar to the one of a natural flooding as the people will lose their homes due to the increase in water level. Hence, this technological disaster is clearly much more comparable to a natural flooding event than for example to the technological disaster of a chemical accident in a plant.

Analysing the homelessness generation of the different disaster types Figure 2.4 distinguishes between direct and indirect homelessness or the combination of both. This distinction was introduced to account for the different underlying processes: Whereas direct homelessness is mostly generated by a sudden event the generation of indirect homelessness is usually of slow onset. Direct homelessness is marked in orange and refers to disasters which destroy homes and thereby leave people without shelter. By contrast the term indirect homelessness is used for people which end up without a shelter as they have to leave their homes – even though it is undamaged – due to the disaster situation. An example is a severe drought in which people have to move to a different location in order to get food. Indirect homelessness is highlighted in green. The combination of both types of homelessness is shown in yellow and applies for example for a war in which people become homeless due to the destruction of their homes or banishment and escape. Beside biological and technological disasters as well as the hydro-meteorological event of extreme temperatures all other disasters either evoke direct or indirect homelessness so that homelessness can be said to be a severe and frequent consequence of disasters which needs tackling.

Having given a general overview of homelessness generation for all feasible disaster cases succeeding only natural disasters will be regarded. The restriction to natural disasters makes sense as the disaster situations of social disasters are different from those of natural disasters and hence the needs of the homeless and the requirements for emergency shelters are diverse. Aiming to account correctly for this differences would necessitate a completely independent research on the disaster context which exceeds the possibilities of this work. The subsequent risk analysis will only deal with the eight natural disasters with direct homelessness as shown in Figure 2.4 in order to regard a relatively uniform need profile of the homeless. The difference in underlying processes for indirect homelessness results in a difference in needs so that an omission of drought seems reasonable for the scope of the work.

2.2.2 Data Source for Risk Analysis

Having defined the eight natural disasters which lead to direct homelessness this chapter will deal in detail with the related numbers of homeless. For this purpose historical data of the database EM-DAT was utilised. The database is generated by the Centre for Research on the Epidemiology of Disasters (CRED) of the Université Catholique de Louvain which collaborates with many international institutions such as the United Nations (UN), the International Committee of the Red Cross (ICRC) etc. It provides the number of homeless for each single natural disaster plus information on the disaster magnitude such as wind speed and Richter scale magnitude. The complete dataset for the before mentioned types of natural disasters was analysed and the results will be presented in the following chapters[10].

Due to the long return period of natural disasters data of a 25 year period (1980-2004) was evaluated. For the low frequency events earthquake, tsunami, volcanic eruption and wave/surge the period was extended to 40 years (1965-2004). In the EM-DAT database the previously distinguished disasters tsunami and wave/surge are displayed in a joint table. This is of no problem for the analysis as the consequences of both disaster types are very similar and only the different natural triggers gave way to the previous distinction. Subsequent the two disasters will be combined under the title 'wave/surge'.

In order to allow for a calculation of the homelessness relating to the inhabitants of a region or a country population data of the UN's Demographic Yearbook was utilised[11]. Because of the long observation period of 25 resp. 40 years, the data on the mid-period population if available was used, i.e. of 1992 and 1984.

2.2.3 Analysis of Homelessness for Disaster Types

Analysing the historical data first of all the general split of the number of homeless for the seven considered natural disasters will be regarded. Figure 2.5 indicates the number of homeless per year per million (mio.) inhabitants as it occurred worldwide in the treated period. It can be seen that there is a large difference between the number of homeless evoked by the different disaster types varying from 671.51 homeless per year per mio. inhabitants (flood) to 0.93 (wildfire). Hence the risk to become homeless by the different natural disasters is very different. In decreasing order flood is followed by windstorm (265.76) and earthquake (71.45). For wave/surge it has to be annotated that of the absolute number of 1.08 mio. homeless 1.03 mio. were caused by the tsunami in South-East Asia in 12/2004. Hence, nearly all homeless of wave/surge were evoked by one single, very exceptional event. As severe as this event was, comparing the numbers of Figure 2.5 it does not seem reasonable from the point of view of homelessness generation to concentrate so much attention and money on the prevention and preparedness of wave/surge but to spread it as well on other disaster types for which the risk is much higher.

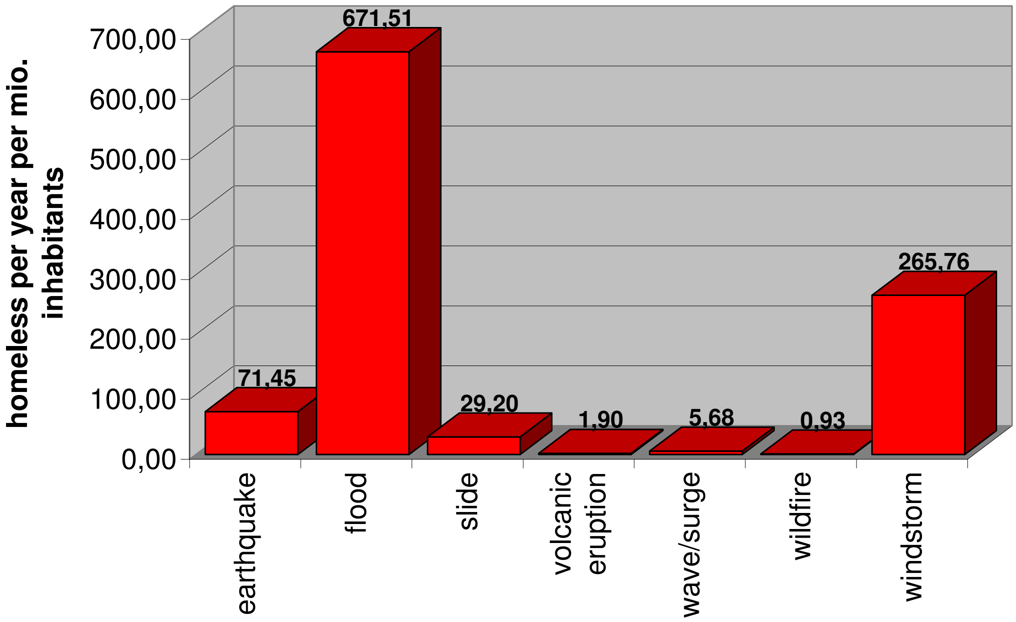


Figure 2.5: Homelessness by disaster types

2.2.4 Analysis of Homelessness for Regions

After regarding the number of homeless with respect to the disaster type this chapter will make a first connection to their location of occurrence on a regional level. For this purpose the world's continents were split in subparts, so called regions. Appendix A.1, Table A.1 gives a list of the countries that form each region. Attention should be paid to the regional split of Europe which assigns some countries to groups to which they no longer belong due to the recent changes in the political situation in Europe. This, for the actual situation wrong categorisation is mainly owed to the fact that at the beginning of the regarded period no distinction between the now independent states of the former Soviet Union was made and hence an evaluation became only possible regarding the entirety of the Soviet Union over the whole observation period. The same applies for the datasets of Yugoslavia and Czechoslovakia. In contrast, Germany and Yemen reunited during this period and in both cases the previously two countries are united in one dataset. The dataset of China also includes Taiwan.

Figure 2.6 shows that there are large differences in the number of homeless per year per mio. inhabitants for the different regions. It varies from 19 in the European Union up to 1 811 in South Asia. It has to be noted that Asia, with the exception of West Asia, faces by far the highest risk of homelessness. In contrast the risk in the European Union is the lowest followed by North America, South Africa and the Former Soviet Union.

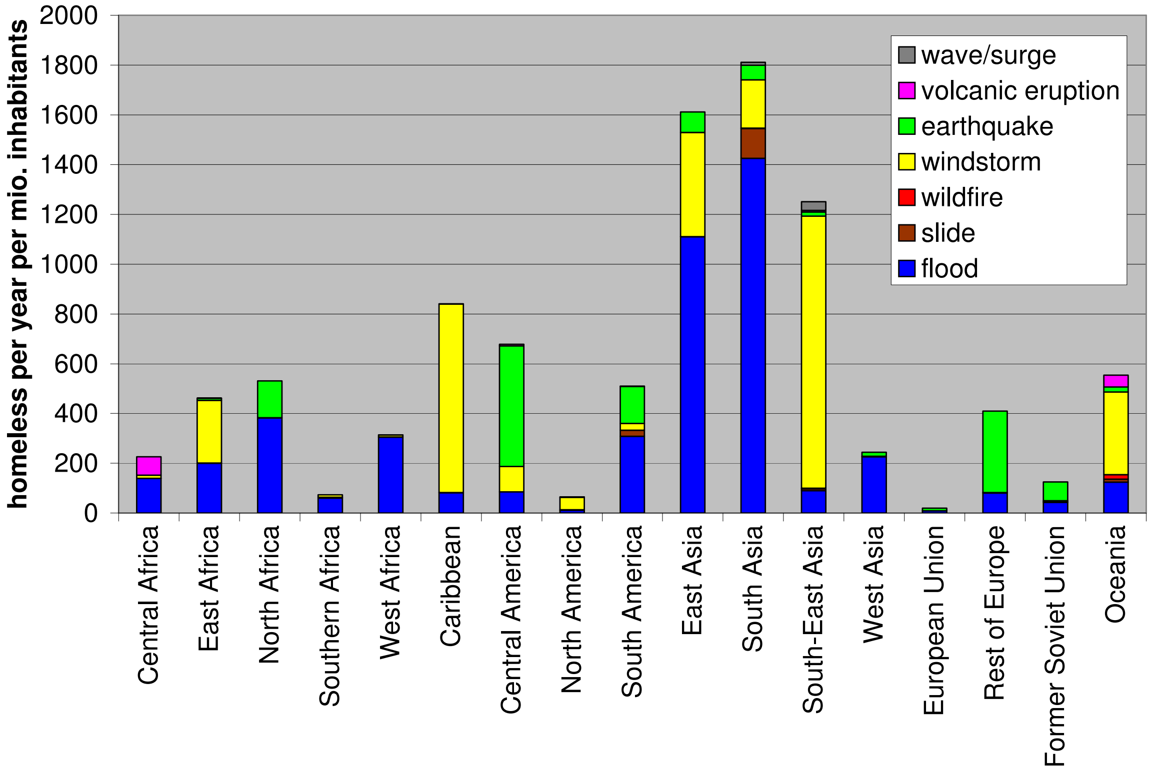


Figure 2.6: Homelessness by regions

This leads to the thesis that the development status largely contributes to the generation of homelessness: While the first world countries of the EU and North America show low homeless numbers the opposite applies for the developing countries of Asia. Further down this thesis will be reinforced by the developed risk index for earthquakes for which a correlation between the human development index (HDI) and the number of homeless is proved (see Chapter 2.3.3).

Furthermore, a large difference in the spread of the various disaster types in the regions can be observed: in some regions most of the homelessness is generated by floods, in others by earthquakes and windstorms. Some regions show one predominant type of disaster e.g. flooding in West Africa, whereas others face a multiple hazard threat like South Asia. This indicates the regionally very diverse endangerment by the various natural disaster types. Setting the absolute numbers of Figure 2.6 for each region to 100%, the percental split of the homelessness occurrence for the different disaster types in each region is obtained as shown in Figure 2.7. In many regions flood contributes the highest percentage, followed by windstorm and earthquake. This result corresponds to the one of the previous chapter by identifying with regard to the number of homeless the same disasters as most severe.

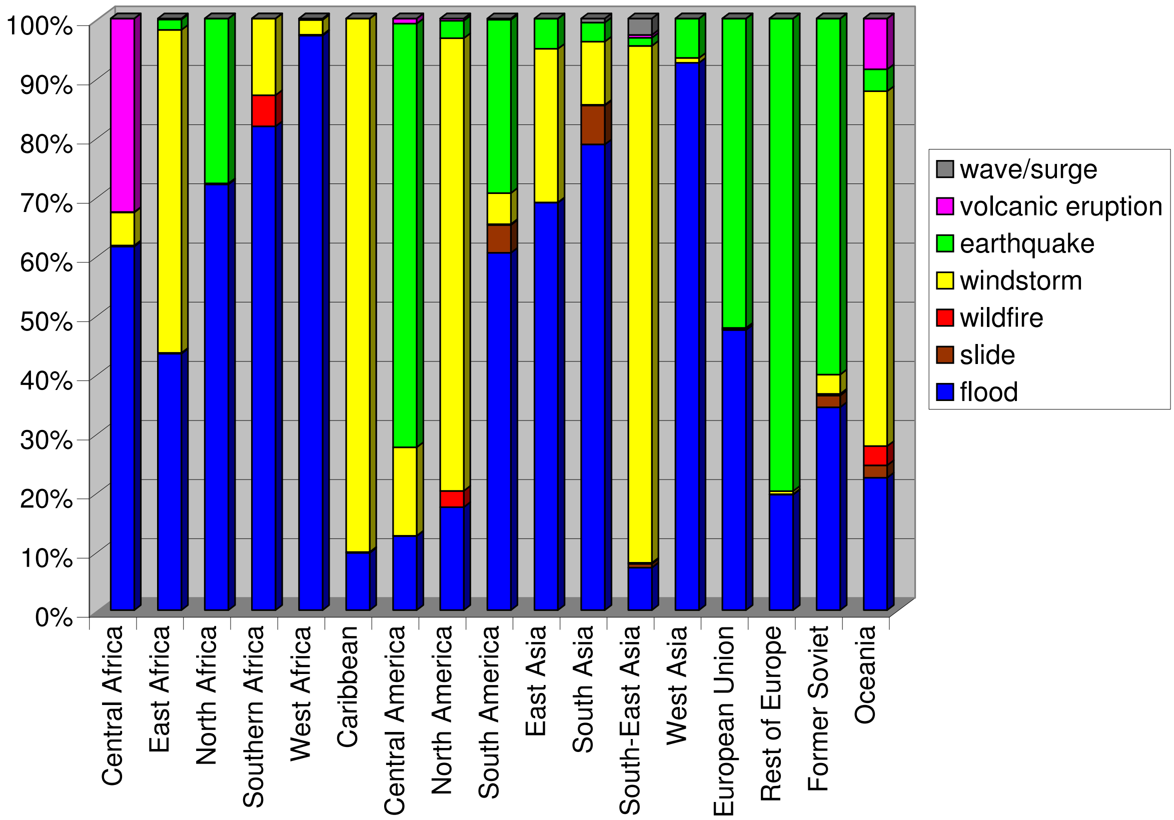


Figure 2.7: Percental split of disaster types per region

In the following the regional distribution of homelessness for both the absolute and the relative number shall be evaluated for each disaster type separately (see Appendix A.2, Figure A.1 to A.7). The term absolute homelessness is used for the number of people that became homeless in the regarded region per year. For the relative homelessness the absolute number of homeless is transformed by dividing it by the region's inhabitants. Thereby a comparison between regions with a large number of inhabitants like South Asia and those of a small population like Oceania becomes possible. Table 2.1 summarises the results of Figure A.1 to A.7. The disasters are given in the order of a decreasing number of homeless. Column 3 indicates the number (no.) of regions in which zero homelessness (homel.) is registered which allows to distinguish between a global and local disaster type. Column 4 gives the number of regions with a relative (rel.) homelessness of higher than 1 000 which can be seen as an indicator for the spread of high homelessness occurrence.

Disaster type	**Fig.**	**No. regions with zero homel.**	**rel. homel. >1000**	**Comments**
flood	A.1	0	15	East and South Asia: extremely high absolute and relative numbers ; absolute results for the two regions ten times higher than for all other
windstorm	A.2	1	10	East Africa, Caribbean, South-East Asia and Oceania: very high relative homelessness due to little population
earthquake	A.3		10	–
slide	A.4	3	3	extremely high homelessness South Asia; 144 651 of 144 788 homeless in South Asia arose in India; of the 3.62 mio. homeless nearly all emerged from two severe slides in India (1986: 2.5 mio., 1995: 1.1 mio.)
wave/ surge	A.5	12	2	one very severe event in 40 years observation period: 1 033 394 of the 1 076 644 homeless in Asia arose from the tsunami in 12/2004
volcanic eruption	A.6	7	2	Central Africa and Oceania: comparatively very high relative homelessness
wildfire	A.7	5	1	lowest absolute and relative homelessness of all disaster types

Table 2.1: Evaluation of figures on regional split of homelessness

It can be seen that in between the disaster types large differences in the occurrence of homelessness exist. The same applies for the regions. Hence, the risk to become homeless due to a natural disaster varies largely with the disaster type and the region.

2.3 Development of a Risk Index for Homelessness

The previous risk analysis has been used to get an understanding of the spread of homelessness over different disaster types and regions. But what are the reasons for the generation of homelessness, for the observed spread? This chapter will show how special factors influence the number of homeless by connecting the previously used dataset with these factors. Then the gained knowledge about the influencing factors will allow their usage for the formulation of the countrywide risk of homelessness i.e. to develop a risk index.

The risk formula indicates the factors which influence the generation of homelessness i.e. hazard, vulnerability and exposure. In correspondence to Figure 2.1 ***hazard*** means a natural disaster of type and magnitude which can cause homelessness or, for the case of the evaluation of historical data, the measured disaster magnitude. These values can be either obtained from hazard maps or from the given disaster magnitude of the EM-DAT data. With regard to the structural damage to homes that leaves people homeless ***vulnerability*** was defined as the susceptibility of homes to destruction. This, later on termed structural vulnerability, is largely generated by the socio-economic conditions as they influence the building quality, building standards, location of homes etc. Chapter 3 will show this dependence in more detail. The socio-economic conditions can be represented by the HDI, with the incorporated GDP (Gross Domestic Product) index reflecting on the economic conditions and the education index as well as the life expectancy index reflecting on the social conditions. Furthermore, the approach to use the HDI seems promising as the UNDP's Disaster Risk Index showed already the large influence of the HDI and GDP on the number of death after natural disasters[12]. Therefore, the HDI will be used in the subsequent as a representative of vulnerability[13]. ***Exposure*** means the number of people living in vulnerable homes. For the purpose of a qualitative statement it could be redefined more generally to be the number of people living in the affected area. However, in the EM-DAT datasets the exposed population is not noted. Furthermore no data on the worldwide population in hazardous area is available. Therefore, the contribution of exposure can not be evaluated in the following.

Of the 7 previously regarded natural disasters subsequent only the three with the highest number of homeless i.e. flood, windstorm and earthquake qualify for further consideration as only their high numbers of victims and events allow for a reasonable analysis.

2.3.1 Influence of Disaster Magnitude

Aiming to evaluate the influence of the disaster magnitude the natural disaster flood disqualifies as the given disaster magnitude of square kilometer flooded area is not a certain magnitude of a destructive force like in the case of a wind speed and an earthquake magnitude. It expresses the size of the affected area and thereby allows conclusions about the number of people living in the affected area i.e. the exposure situation which is not of concern here.

Evaluating the influence of disaster magnitude for windstorms by plotting the number of homeless per event against the wind speed in km/h no correlation could be found. Therefore, subsequently only the influence of the earthquake magnitude will be analysed in detail.

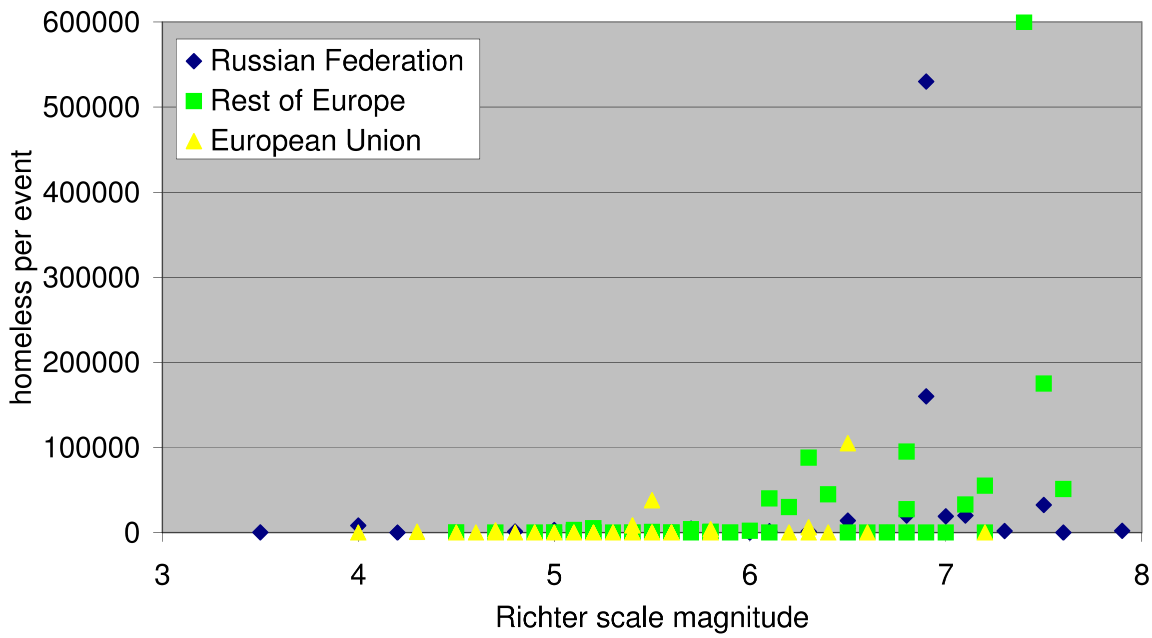


Figure 2.8: Homelessness by Richter scale magnitude

Influence of Earthquake Magnitude

Plotting the number of homeless per event against the Richter scale magnitude it could be found out that a high homelessness is usually only evoked for a Richter scale larger than 6 (see Figure 2.8 and 2.9). Furthermore, for many regions the number of homeless increases with the disaster magnitude (see Rest of Europe). Many events of all feasible disaster magnitudes feature zero homeless. This can be explained by the influence of the exposure as the affected area might be unsettled or scarcely settled so that no one can become homeless.

It has to be noted that in some cases the given Richter scale magnitude does not correspond with the occurring structural damage. This can be explained by a number of shortcomings which derive from the fact that the historic data of EM-DAT provides the disaster magnitude as the maximal Richter scale magnitude. However, the occuring damage is not only depending on the maximum magnitude but as well on the number of tremors. An example for this is an earthquake in Yemen in November 1991: its maximum Richter scale magnitude was 4.0 and initially 17 houses were destroyed[14]. During the following months aftershocks with a magnitude of up to 3.5 continued, destroying or damaging 11 900 homes as the structures were gradually weakened by the continuing tremors. Fearing the destructive power of the tremors, 217 000 people camped outside their homes for months and consequently were in need of temporary shelters. Therefore, a more precise analysis might be possible if the disaster magnitude included aftershocks.

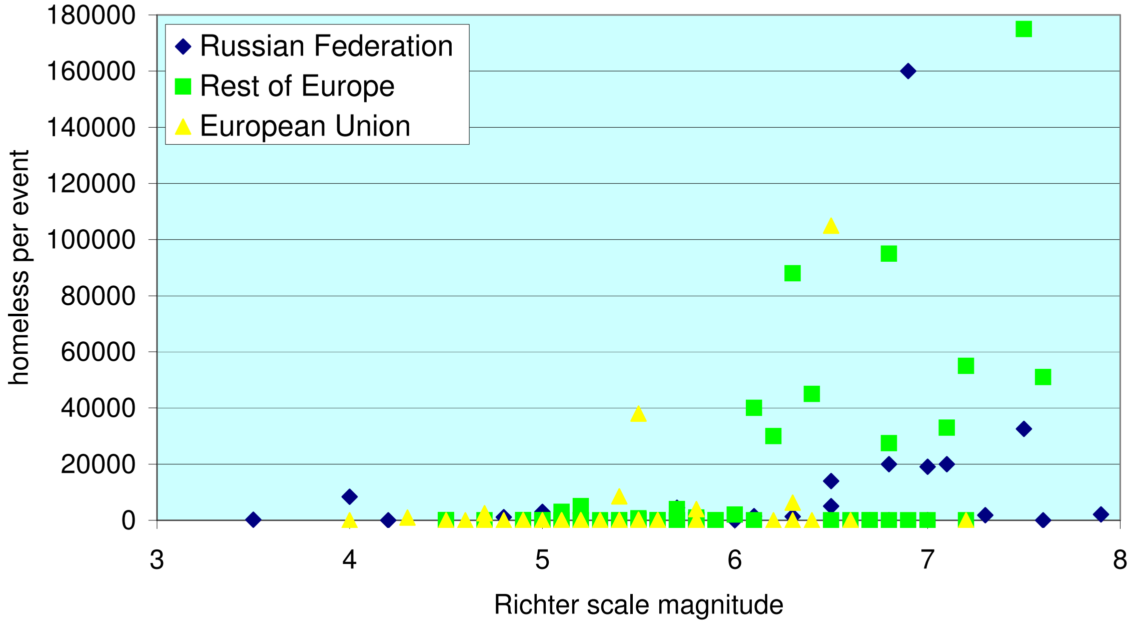


Figure 2.9: Homelessness by Richter scale magnitude (zoom)

Furthermore, the given value of Richter scale magnitude is relatively imprecise with respect to the resulting damage in the built environment. A better prediction could be obtained if the modified Mercalli scale, which as an intensity scale provides the impact of earthquakes on the built environment, would be used. Therefore, developing a risk index for earthquakes, in Chapter 2.3.3 the more adequate measure of the modified Mercalli scale will be utilised.

2.3.2 Influence of Socio-economic Conditions

Having seen in which way the disaster magnitude influences the number of homeless this chapter shall analyse the importance of the socio-economic conditions represented by the HDI. The data on the HDI was obtained from the Human Development Report 2005[15]. Due to the political changes in the former Soviet Union the data only comprises the HDI of the Russian Federation which was, as a best fit, consequently matched with the Soviet Union disaster data[16]. For the purpose of categorisation the HDI values are associated with the following three stages of human development:

low human development: $\text{HDI} < 0.5$

medium human development: $0.5 \leq \text{HDI} < 0.8$

high human development: $0.8 \leq \text{HDI} \leq 1$ [17]

	per disaster	
HDI	**deaths**	**damage**
low	1052	79 mio. US$
medium	145	209 mio. US$
high	23	636 mio. US$

Table 2.2: IFRC Study on deaths and damage depending on HDI [IFRC, 2006]

	per disaster			**absolute**	**percentage of**
HDI	**deaths**	**damage**	**homeless**	**homeless**	**total homeless**
low	511	31 mio. US$	46896	14.6 mio.	18.3 %
medium	160	193 mio. US$	53488	63.9 mio.	80.0 %
high	18	474 mio. US$	2015	1.3 mio.	1.7 %

Table 2.3: Deaths, damage and homelessness depending on HDI

A study by the International Federation of Red Cross and Red Crescent Societies (IFRC) analysing 2 557 natural disasters between 1991 and 2000 showed already the dependency of death resp. monetary damage and HDI[18]: low human development (HD) is associated with a high number of death per disaster whereas the monetary damage increases with higher scores on the HDI (see Table 2.2). To get to know about the distribution of homelessness the EM-DAT data from 1991 to 2000 was evaluated for the 7 natural disasters which were identified to generate homelessness[19]. A HDI from 1995 or, were not available, from more recent years was used. As for some countries no data on the HDI was given at all, the data of these countries was omitted in all evaluations where the HDI was requested. Although the IFRC study used the EM-DAT data of all 12 defined natural disasters the results obtained for the distribution of death and monetary damage for the here analysed 2 173 disasters are comparable (see Table 2.3). The number of homeless per disaster is highest for countries of medium HD (53 488) closely followed by low developed countries (46 896). With 2 015 the number of homeless in highly developed countries is significantly lower. Regarding the absolute number of homeless which was registered during the 10 years 80 % of the homeless lived in medium developed countries. It has to be noted that of the 63.9 mio. homeless 48.7 mio. occured in China so that this result is largely dependent on the categorisation of China as a medium developed country. Without its contribution the absolute number of homeless for low and medium HD is nearly the same. Only 1.7 % of the homeless come from countries of high HD. Therefore, it can be concluded that in contrast to the number of death the number of homeless is not decreasing with increasing HD but tends to increase stepping from low to medium HD before decreasing significantly moving to high HD. Hence homelessness as a consequence of natural disasters can be seen to be predominantly a problem of countries of lower HD.

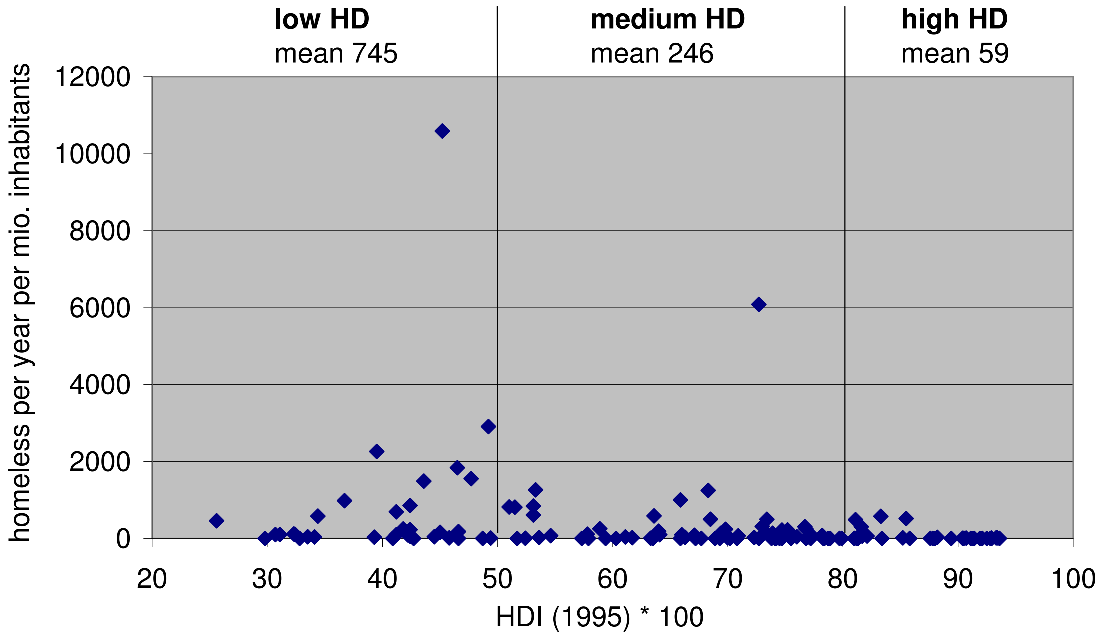


Figure 2.10: Flood: homelessness depending on HDI

After this very general view upon the dependence of HDI and homelessness in the subsequent a disaster specific analysis for flood, windstorm and earthquake will evaluate in which way the HDI influences the number of homeless of a country. For this purpose the number of homeless per year per mio. inhabitants (relative homelessness) of each country was plotted against its HDI. A HDI of the mid-observation period was used i.e. from 1985 for earthquake and from 1995 for flood and windstorm. Where the corresponding data was not available a HDI of more recent years was used. Figure 2.10 and 2.11 show that for floods the number of homeless decreases for increasing HD. The single, extremely high number of homeless (i.e. 10 590) in the low HDI section represents Bangladesh which is, unfortunately, known for severe floods.

For windstorms a completely different distribution is obtained with the higher values clustering in and around the section of medium HD (see Figure 2.12). The high number of homeless in the high HDI section (i.e. 20 725) represents Tonga where during the 25 year observation period 50 000 people became homeless due to windstorms. This number leads to a very high relative homelessness as the population of the country is very small (i.e. below 100 000). Together with the fact that Tonga cannot be understood as a typical first world country this value shall not be overestimated. Therefore, the mean value of relative homelessness for high HD was calculated once with Tonga leading to 641 and without it leading to 126. Excluding Tonga a result which is qualitatively comparable to the previously presented evaluation of homelessness per disaster (see Table 2.3) is gained

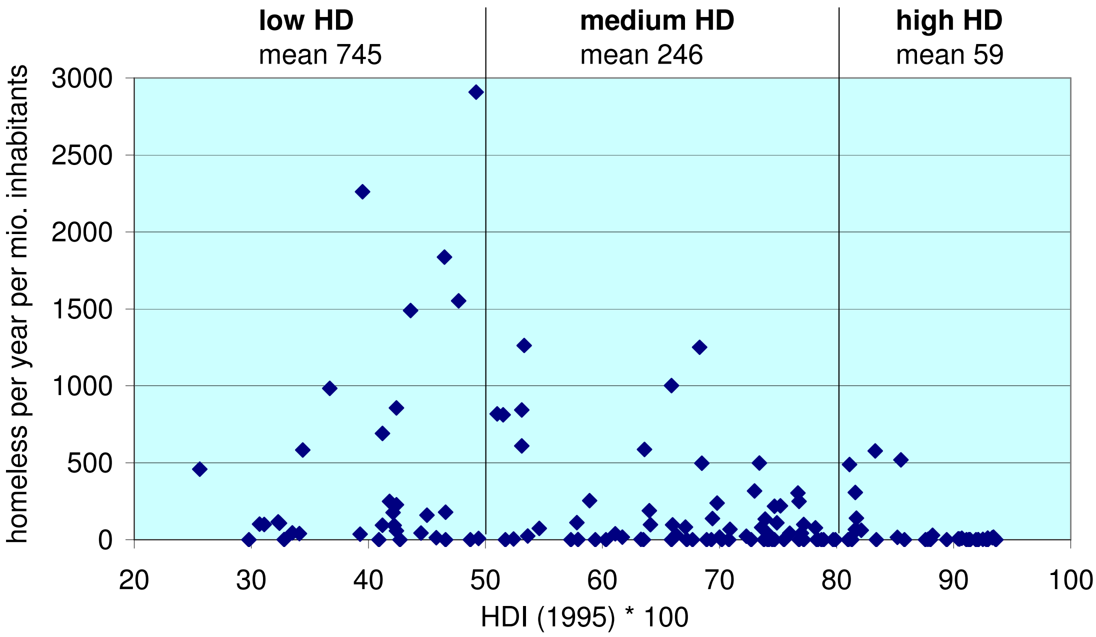


Figure 2.11: Flood: homelessness depending on HDI (zoom)

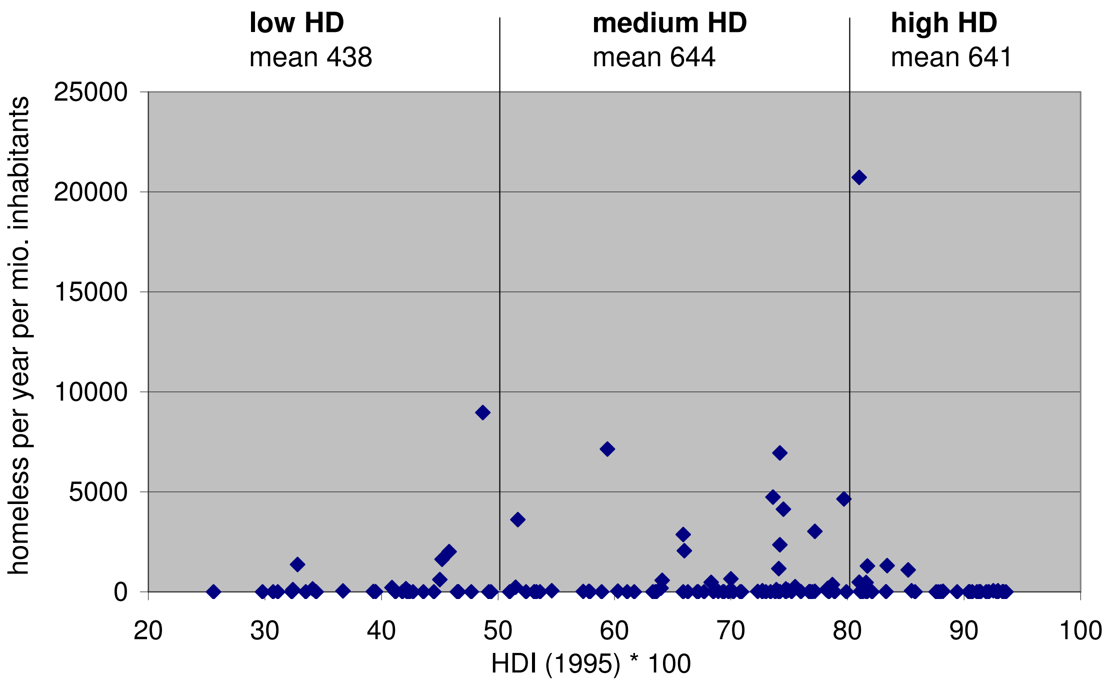


Figure 2.12: Windstorm: homelessness depending on HDI

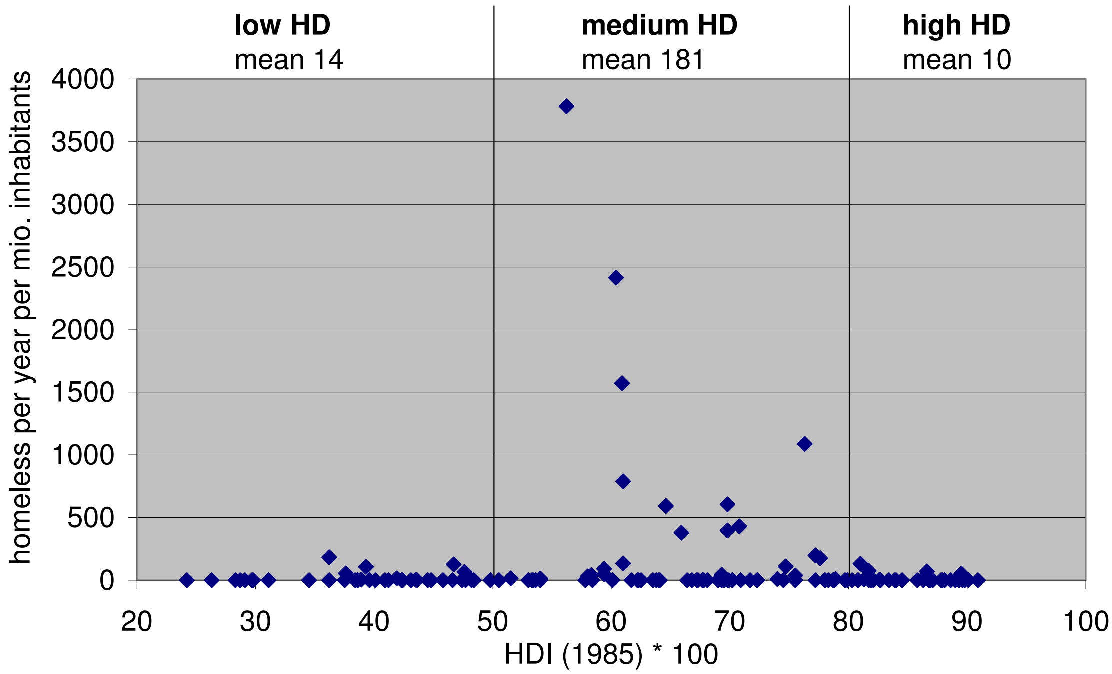


Figure 2.13: Earthquake: homelessness depending on HDI

with the highest value for medium HD, a lower value for low HD and a significantly lower value for high HD. For earthquakes, as seen in Figure 2.13, all high numbers of homeless lie in the section of medium HD. The mean for medium HD is more than 10 times higher than the one for low or high HD.

Regarding the provision of emergency shelters the above findings underline the importance of emergency shelters in countries of low and medium human development. In conjunction with the findings of Chapter 3, which shows how the socio-economic boundary conditions and therewith the development status influence the specific needs for emergency shelters, the subsequently performed focus on emergency shelters for countries of low and medium human development becomes reasonable. A restricting focus on special disaster types does not seem necessary – even though the number of homeless varies strongly for the different disaster types – as the influence of the trigger is far less significant for the provision of good sheltering solutions as Chapter 3 will show as well.

2.3.3 Risk Index for Earthquakes

Having shown the contribution of disaster magnitude and socio-economic conditions previously the gained knowledge shall be used to develop a risk index for homelessness. Of the three natural disasters with a high number of homeless only earthquake will be dealt with. Both flood and windstorm are missing the contribution of the disaster

Risk class	NATHAN zone	MM
0	zone 0	≤ 5
1	zone 1, small areas zone 2	6/7
2	large areas zone 2	7
3	small areas zone 3	8
4	$\geq$ large areas zone 3, small areas zone 4	≥ 8

Table 2.4: Definition of risk classes

magnitude to the risk description, as an analysis on the influence of disaster magnitude of floods did not seem useful and no correlation between the number of homeless and the disaster magnitude could be found for windstorms. Therefore, the development of a risk index for floods and windstorms was not possible.

Risk Classification due to Hazard Intensity

The shown correlation between Richter scale magnitude and number of homeless leads to the assumption that it might be possible to predict homelessness by means of the expected hazard intensities. The data of the hazard intensity is taken from the natural hazard maps of NATHAN (NATural Hazards Assessment Network), a tool of the Munich Re for geographical underwriting of natural hazards[20]. NATHAN distinguishes 5 zones of modified Mercalli scales (MM) ranging from MM 5 and below in Zone 0 up to MM 9 and above in Zone 4. Comparing the Mercalli zones at the location of earthquakes with the number of homeless no correlation could be found. This can be explained by the fact that the hazard intensity is not the only parameter influencing the obtained number of homeless. Exposure and vulnerability also play a major role so that such a direct linkage cannot be found. However, on a qualitative level the proof of an interdependence seems possible allowing thereby for variations due to exposure and vulnerability. Using this approach the focus on the single disaster event was left and the hazard intensity estimated for each country. Five risk classes based on the Mercalli zones of NATHAN were defined as given in Table 2.4.

A risk class was assigned to each country and the number of homeless per country, year and mio. inhabitants plotted against the risk class. Figure 2.14 shows the significant increase in the average number of homeless for higher risk classes. Hence, the comparison between the risk classes and the historical data proves that the risk of becoming homeless is much higher for countries that were categorised in a high risk class. The variation in the number of homeless for one risk class can be explained by the fact that the influence of exposure and vulnerability was not taken into account. Nevertheless, it is obvious that for a country in a high risk class the risk of homelessness is much higher than for those in a lower risk class. Hence, the assignment of risk classes to each country as shown in Appendix A.3, Table A.2 and A.3 can be used as a risk index for the homelessness

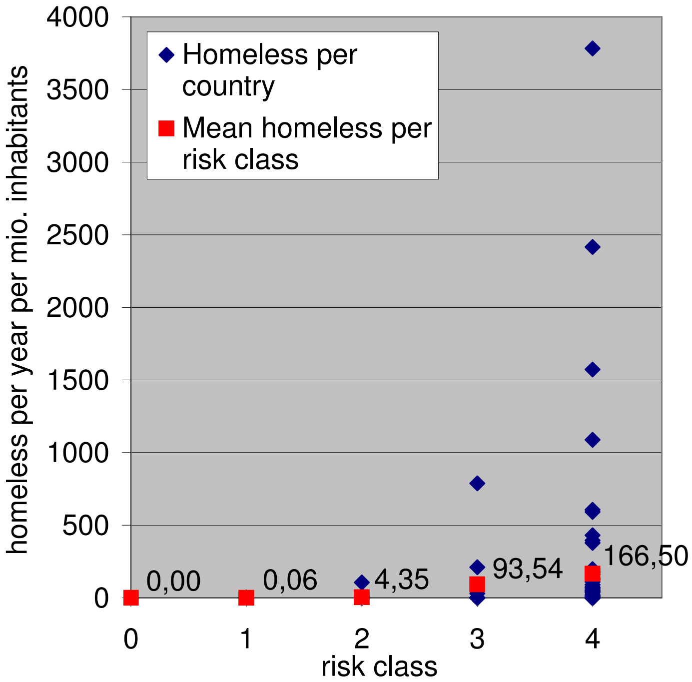


Figure 2.14: Homelessness depending on earthquake risk class

due to earthquake.

Risk Classification due to Socio-economic Conditions

Having observed in Chapter 2.3.2 significant differences in the number of homeless for different stages of HD it shall now be analysed whether this is also true for the countries in risk class 4. Given a positive result it would become possible to further specify the risk of those countries which from the hazard point of view have been assigned the highest risk. The used HDI data is the same as above (see Chapter 2.3.2). Figure 2.15 shows for the countries of risk class 4 a distribution similar to the one for all countries (see Figure 2.13) with the mean for medium HD being more than 10 times higher than the means for low and high HD. However, the means for the countries in risk class 4 are much higher than the ones for all countries which can be explained by the presumably higher disaster magnitude that will have been associated with the events in countries of risk class 4. The comparability of the distributions shows that for all HD stages events with lower numbers of homeless are omitted stepping from all countries to the countries of risk class 4. However, for the countries of high HD unproportionally many low homelessness events are omitted as its ratio to the medium HD mean decreases and its mean exceeds the one for low HD. Hence, it can be stated that either for low risk classes due to the good building quality unproportionally little damage occurs in

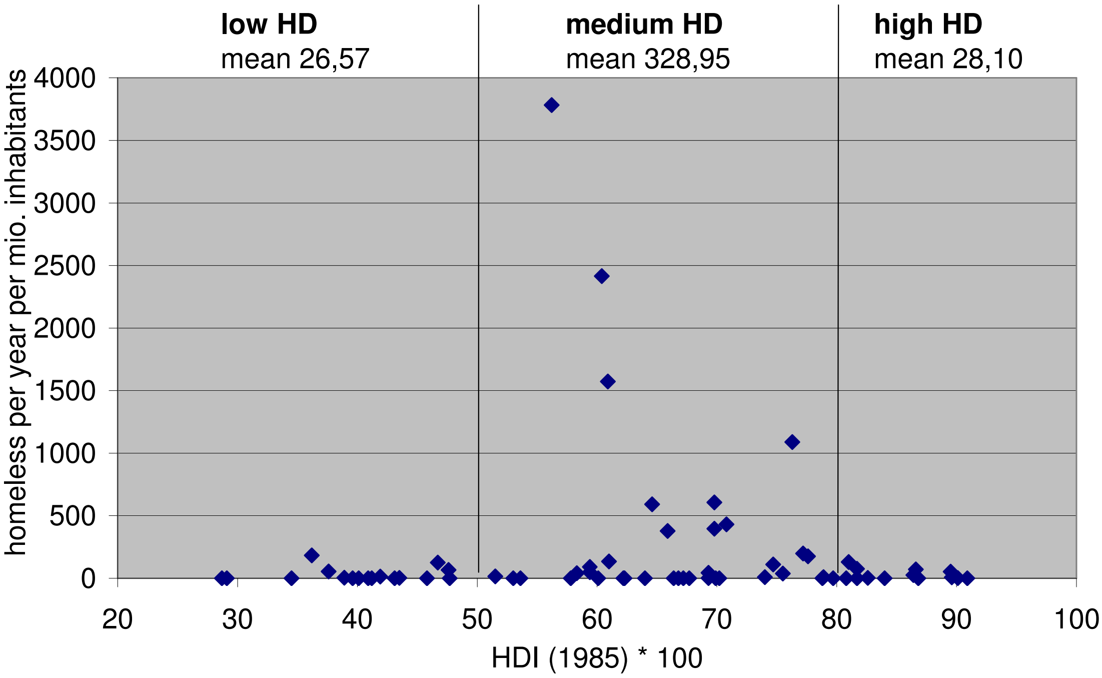


Figure 2.15: Homelessness depending on HDI for earthquake risk class 4

highly developed countries or that for high risk classes the building although of good quality can no more withstand the intensive disaster magnitude. In general the shown distribution of a not continuously decreasing number of homeless with increasing HD might be astonishing as one might assume that with higher HD the building quality increases, i.e. the houses become less vulnerable. Considering the local conditions of low and medium developed countries in more detail, it becomes evident that people in countries of fast urban growth with high population densities in disaster prone areas (i.e. medium developed countries) are much more vulnerable than those in poorer countries with traditional structures and low population densities in mainly agricultural areas (i.e. low developed countries).

The significant differences in the means between the different stages of HD show clearly the large contribution of the socio-economic conditions to the generation of homelessness. The findings can be used to enhance the above developed risk index by adding the human development status which leads to the risk matrix as given in Figure 2.16 with the redder the color the higher the risk. The final result of the analysis is given in Appendix A.3, Table A.3 which identifies the countries with the highest risk of homelessness due to earthquakes.

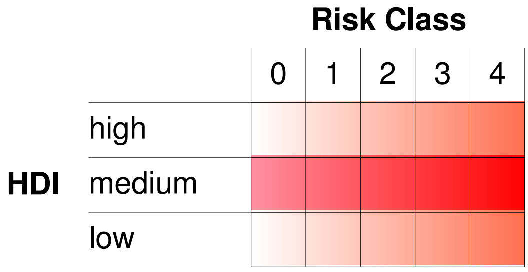


Figure 2.16: Risk matrix for earthquakes

Notes

[1]Schleswig-Holstein: federal state in northern Germany with coast to the North Sea and Baltic Sea
[2]Plate (2001), pp. 11-14; Mertsch (2004)
[3]Augusti (2001), p. 228
[4]Wisner (2004); ISDR (2006)
[5]Augusti (2001), p. 228; Plate (2001), p. 19
[6]Proske (2004), p. 34
[7]EM-DAT (2006); ISDR (2005)
[8]The distinction between man-made and social was introduced in order to avoid a double-usage of one term for two different meanings. In cases where the here specified subgroup 'social disaster' is not dealt with it might be found that the here used term man-made is replaced by social (Wisner (2004), p. 4). However, for the further discussion of natural disasters the use of the term man-made seems more appropriate as it is more suggestive.
[9]Wisner (2004), pp. 4-10
[10]EM-DAT (2005)
[11]United Nations Statistics Devision (2005)
[12]UNDP (2004)
[13]Alternatively the GDP might have been used, which – not considering education and life expectancy – accounts slightly more for the economic conditions of the regarded country. However, as HDI and GDP are strongly correlated, no significantly different results would be obtained.
[14]United Nations Department of Humanitarian Affairs (1991)
[15]UNDP (2005)
[16]The continuation of the Soviet Union in the disaster dataset even after the breakdown of communism became necessary due to the observation period (see Chapter 2.2.4)
[17]UNDP (2004a), p. 255
[18]IFRC (2006)
[19]The same EM-DAT datasets as previously were used (see Chapter 2.2.2). Only the evaluation period was here restricted on the data from 1991-2000
[20]Munich Re (2006)

Chapter 3

Impact of Vulnerability on Sheltering Options

3.1 Contribution of Socio-economic Conditions – Comparison between Elbeflut and Somaliaflood

Often the main distinction for the analysis of the consequences of natural disasters is the type of disaster. However, analysing homelessness and its characteristic in different disaster cases it can be found that the contribution of the disaster type to the local characteristic of homelessness is comparatively small. In contrast to this, the post-disaster situation is largely depended on the specific socio-economic conditions of the country and local area of affection. They cause a certain degree of vulnerability which strongly influences both the demand for temporary accommodation and the available sheltering options.

To illustrate this statement the following example of the two severe flooding events of the Elbeflut in Germany in 2002 and the Somaliaflood in 1997 shall be given, which features countries with very different socio-economic conditions. It demonstrates that the same type of disaster can result in completely different sheltering situations as the brief summary of key factors in Table 3.1 underlines. For both countries the events meant very severe floodings as a major river inundated large areas (see Figure 3.1)[1]. Hence, the natural setting is similar. The same applies for the exposure as in both cases the flooded regions were settled so that a large number of homes and their inhabitants were affected[2]. However, already the level of prevention and preparedness before the disaster was very different: Germany features a lot of well maintained dams, disaster plans, early warning possibilities etc. as compared to other countries. Nevertheless, this does not necessarily mean that the reached level of prevention and preparedness is generally viewed as sufficient as the wide discussion and criticism after the Elbeflut showed[3]. In contrast the situation in Somalia was characterised by the unstable conditions of many

	Elbeflut 2002	**Somaliaflood 1997**
natural event	major river floods large areas of many km^2	major river floods 600 km^2
prevention	maintained dams, disaster management plans, early warning systems etc.	poor condition of dams, no working local authority
response	extensive response by THW, Bundeswehr etc.	very limited up to no response; affected population difficult to reach due to bad condition of infrastructure
result of prevention/ response	extent of structural damage limited; fast return into homes	extended flooding, which lasts for months
temporary accommodation	evacuees live with relatives, friends or in public buildings; no need for tents	people wait on higher elevations in pouring rain; some plastic sheets distributed; tents would be improvement
reconstruction	fast; public and private financial means, insurances	no help, as focus on development of livelihood; no financial means

Table 3.1: Comparison between Elbeflut and Somaliaflood

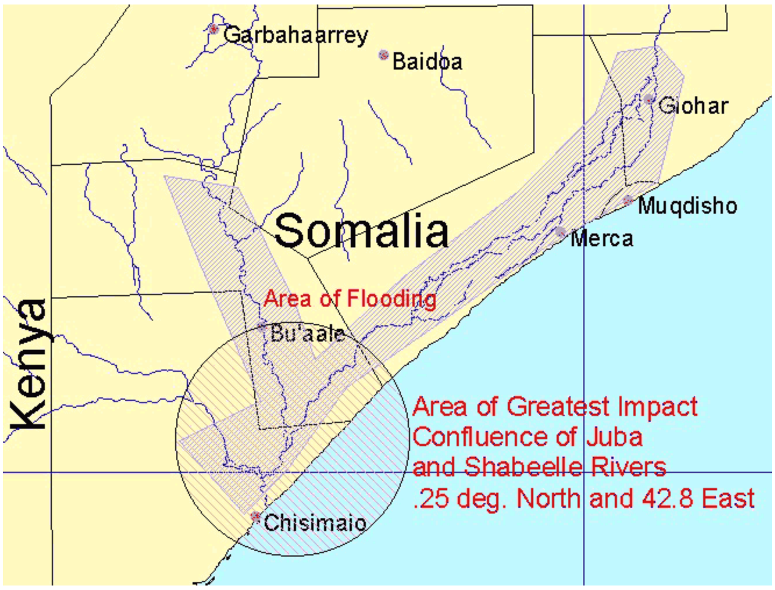


Figure 3.1: Flooded area of Juba and Shabeelle Rivers, Somalia [USAID, 1997]

Figure 3.2: Dam construction by Bundeswehr and volunteers in Geesthacht, Lauenburg [Elbetreff, 2002]

years of civil war which left the dams in extremely poor conditions and destroyed local authorities[4].

Once the disaster stroke, Germany managed a fast response to the flooding. In Somalia, in contrast, there was nearly no response which led to large differences in the extend of structural damage. Along the Elbe many homes could be saved from destruction or damage due to preventive measures and the vast response of the THW (Technisches Hilfswerk), Bundeswehr, fire brigades etc. (see Figure 3.2). Sandbags and pumps were used to reduce the extend of flooding whereas in Somalia no help of this type was given and the situation was further exacerbated by the bad condition of the dams. Countless villages were submerged and people gathered in pouring rain on dams which protruded out of the water. As all local buildings were submerged and no access to dryly located buildings further away was possible, the only feasible sheltering option for the people was some type of emergency shelters such as plastic sheets or tents. The given shelter aid was restricted to plastic sheetings which were eventually distributed by boat or helicopter as no other way of access existed with streets washed away and airstrips waterlogged[5]. Due to the restricted number of these means of transport many people were cut off from help for weeks or even months[6]. In contrast, those people along the Elbe which had to leave their homes had access to transport possibilities out of the affected area and usually found accommodation with friends or relatives[7]. A small proportion was accommodated in public buildings like schools, but no one was in need of tents. Therefore, a tent village in Pirna, constructed to house evacuated people, was only occupied by aiders[8].

In the same manner the reconstruction phase shows significant difference leading to very different durations of the stay in temporary accommodation. Whereas in Germany technical means such as pumps allowed a fast drainage of the water, in Somalia it stayed in large parts of the flooded area for months which delayed a possible start of reconstruction[9]. Once the water drained of along the Elbe the reconstruction of homes started as there were sufficient public and private means for reconstruction (see also Chapter 3.3.3). In Somalia no financial means for the reconstruction of homes were available and the given help focused on the reconstruction of livelihoods in order to make sure that the people could survive. Due to this more important need the basic need of shelter was not addressed[10]. Hence, the destruction of the home was a by far more serious loss than in Germany as it could not be substituted in short term.

It can be concluded that, although the hazard and the exposure are comparable for both disasters, the difference in the socio-economic conditions and hence in vulnerability led to extremely different sheltering situations and needs after the disasters. For Germany the influence of high human development allowing for preventive measures, a fast and good response and reconstruction as well as for various temporary accommodation options can not be neglected. Considering a different type of natural disaster the shelter response would therefore be similar which confirms the above statement of the low significance of the disaster type. Analogously, the situation in Somalia was dominated by low human development and further worsened by the impact of civil war. The given response was very limited and delayed. The people's sheltering options were poor – if given at all – for a long period of time. Closing the two examples proof, that the main attention must be directed upon the socio-economic conditions and the resulting vulnerability rather than on the disaster type.

3.2 Diagram of Influencing Factors for Shelter Selection

The previously mentioned contribution of vulnerability to the sheltering situation is graphically demonstrated in Figure 3.3. After giving an explanation of the chart its significance will be demonstrate in detail using examples of various disasters.

From top to bottom the left hand side of Figure 3.3 shows the sequence of events starting from the hazardous event that together with structural vulnerability and exposure generates a certain number of homeless. These homeless are subsequently in need of some type of temporary accommodation in which they will finally stay for some period of time. Dividing the figure in three stages (marked I - III), the chart shows the contributing factors that lead to answering the following questions:

I **Why** does somebody need temporary accommodation?

II **Which type** of temporary accommodation will be available to the person?

III **How long** will the person have to stay in the temporary accommodation?

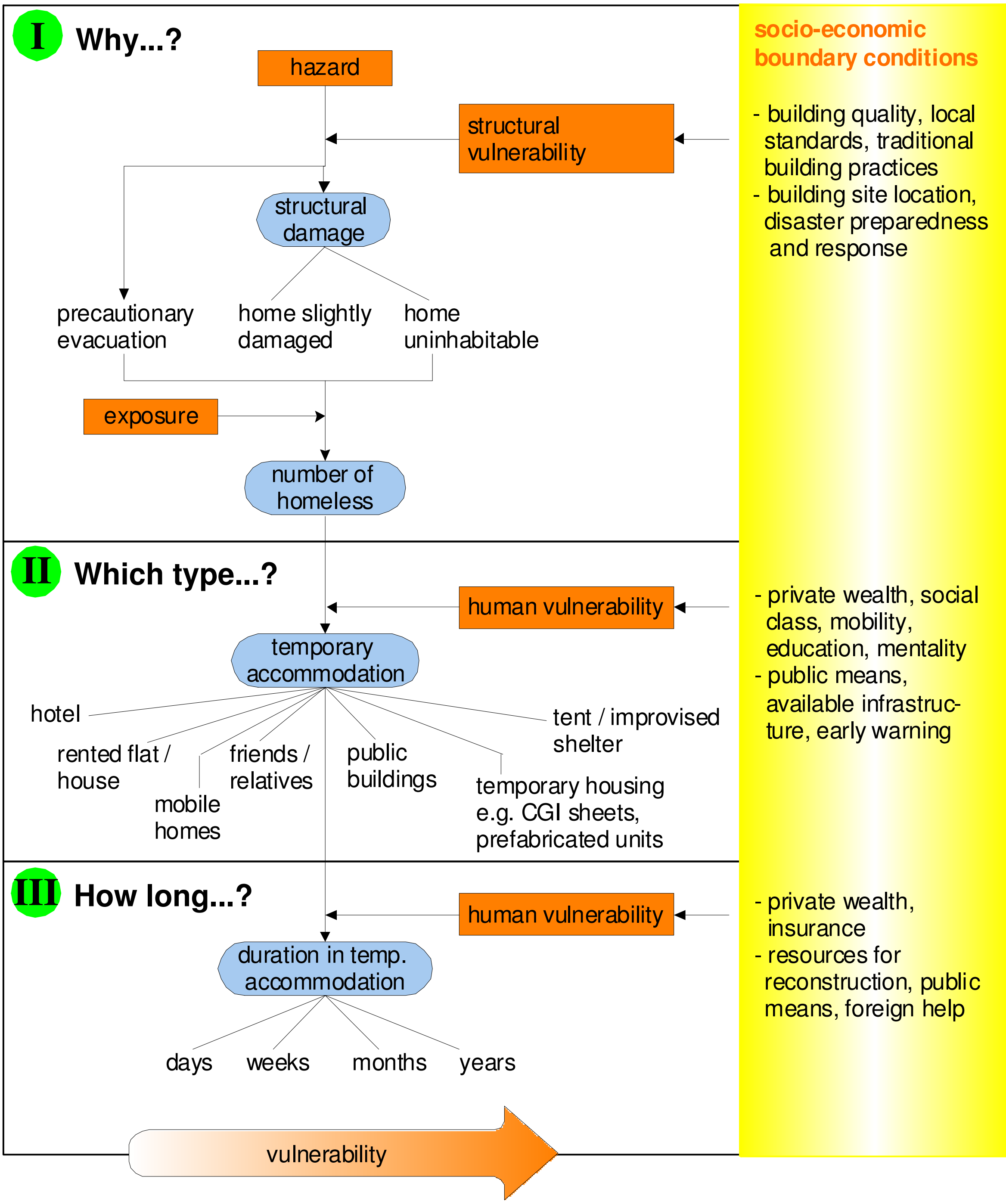


Figure 3.3: Impact of socio-economic boundary conditions on sheltering situation

The right hand side illustrates the contribution of the socio-economic boundary conditions which are dependent on the state of human development and lead either to structural or human vulnerability. Depending on the degree of vulnerability the resulting options in each of the stages are shown. The options are depicted with an increasing vulnerability from the left to the right with the exception of the precautionary evacuation. Its position is only owed to the restriction in drawing possibilities and does not stand for a decrease in vulnerability relative to the possibility of an uninhabitable home. Structural vulnerability comprises all socio-economic factors which influence the structural damage to homes. These factors are firstly the resistance of the house itself against the disaster e.g. its earthquake resistant structure (expressed by building quality, local standards and traditional building practices) and secondly factors that influence the disaster impact on the house such as dams or local use of pumps against flooding (expressed by building site location, disaster preparedness and response). With regard to the factor 'building site location' it has to be noted that the vulnerability of a house on a specific site not only depends on its location with respect to a potential disaster impact but as well on preventive measures that the public authorities will carry out e.g. the construction of dams.

As the hazard impact meets the previously defined structural vulnerability some degree of structural damage will be caused to the homes. Subsequently – depending on the number of homes exposed – a certain number of homeless is evoked due to the uninhabitability of their homes or precautionary evacuation. The precautionary evacuation anticipates some degree of structural damage which can become a threat for the health and live of the inhabitants. It can become necessary both before and after the disaster strikes. Beside the pre-disaster evacuation due to e.g. a flooding event with slowly raising river levels it shall not be forgotten that for example after earthquakes many people prefer not to return to their undamaged or slightly damaged homes in fear of aftershocks. Hence, although they are not in need of temporary accommodation due to the severity of post-disaster damage to their home they still need a shelter for a certain period of time. It shall be noted at this point that a derivation of the options for temporary accommodation purely from the number of homeless is not possible. At the first glance a thought of the following type might arise: with the number of homeless being that high no other sheltering possibility than tents will be given. However, this largely neglects the subsequently demonstrated influence of human vulnerability on the sheltering options so that the preceding conclusion becomes impossible. Further down Hurricane Katrina, which stroke the south of the USA in 2005, will be used as an example to additionally demonstrate the contribution of human vulnerability.

In contrast to the structural vulnerability that is evoked by the socio-economic conditions in stage I, in stage II and III the socio-economic conditions result in human vulnerability. The human vulnerability expresses the ability of the homeless to react on the – possibly only temporary – loss of home. However, human vulnerability has not to be seen restricted on the individual's possibilities but depends as well on its surrounding: for example an immobile old lady in an old people's home in Germany will herself have no ability to evacuate and get to some safe accommodation during the Elbeflut but the public authorities will take care of her and e.g. transport her to some further away old people's home. Consequently, the socio-economic factors defining the options for temporary accommodation and the duration of stay within them can be split in more or less associated with the individual or the public. The wealth, social class, mobility, education and mentality of the individual will restrict the choice of temporary accommodation. The public will contribute via public means, available infrastructure and early warning. The term 'available infrastructure' describes the existence of transport infrastructure such as buses, trains, highways that influence the options for leaving the affected area and the presence of public buildings such as schools that could make up a temporary sheltering option. All of the before mentioned factors together will define whether a person will rent her- or himself a hotel room (at the lowest end of the vulnerability scale) or will be without any shelter until someone delivers her or him a plastic sheeting to make up some poor shelter (at the highest end of the vulnerability scale).

The duration in temporary accommodation is in most cases equal to the time until the completion of reconstruction as only few people migrate for ever to existing homes in unaffected areas. Therefore, the given socio-economic boundary conditions relate only to the possibilities for reconstruction and not to factors which might decide upon moving away for ever such as family status, job opportunities etc. The relevant socio-economic factors are on the one hand the wealth and insurance situation of the individual and on the other hand, associated to the public, the resources for reconstruction, the public means and foreign help. Together they define the human vulnerability that will decide whether a person is going to stay only days or even years in temporary accommodation.

For both stage II and III it has to be kept in mind that although only human vulnerability is depicted as an influencing variable at these stages the variables introduced in stage I are not without influence on the applicable options as the stages of the event sequence follow each other. An example of this is a very extensive damage, be it due to the hazard intensity, the structural vulnerability or the exposure. It requires not only to rapidly reconstruct some homes but to rebuild complete regions with all needed infrastructure, a relocation of the population to safe areas etc. over a long period of time as seen after the South-East Asia tsunami in 2004[11].

3.3 Examples of the Impact of Vulnerability on Sheltering Options

Giving the following examples to illustrate in more detail the impact of vulnerability on the sheltering options as depicted in Figure 3.3 it shall be kept in mind that they can never represent the overall sheltering situation after a disaster but only show how

Figure 3.4: Destruction of historic quarter in Bam [Manafpour, 2003]

special socio-economic factors lead to a specific situation. As in any disaster situation the socio-economic factors will vary largely both from individual to individual and on the public side (due to the large affected area with different local authorities etc.) it is obvious that always a variety of sheltering options will be encountered.

3.3.1 Why does somebody need temporary accommodation?

Asking the question why somebody becomes homeless and hence needs temporary accommodation the Bam earthquake of December 2003 in Iran can be taken as an example for the significance of traditional building practices and building quality. Many houses in the historic quarter were built of mud bricks, clay and stray, leading to a widespread destruction (see Figure 3.4)[12]. Additionally it was observed that some of the larger, stronger institutional buildings resisted the earthquake of a Richter scale magnitude of 6.3, whereas the fragile residential buildings collapsed[13]. This shows that the loss of home was not inevitable but owed to the traditional building practices and bad building quality which left the people – if at all alive – in need for temporary accommodation.

The flooding in Romania in 2005 as part of the severe summer flooding across Europe gave an example of the importance of the building site location. The most affected were poor families as they were living in the areas most exposed to the flood[14]. It points out the often observed linkage between no access to safe land and the risk of becoming homeless. As people are poor they often have to build in unsafe areas and hence it is more likely that they get in need of temporary accommodation due to the destruction of their home. In many cases the situation is worsened by a bad building quality which makes a damage even more feasible or extensive. In the case of Romania this applied for the Roma whose houses were mostly built of cheap, improvised materials so that they were particularly hard hit. For an example of the influence of disaster preparedness and response as well as preventive measures (included in the factor 'building site location') on the structural damage it shall be referred to the comparison of the Elbeflut and the Somaliaflood above (see Chapter 3.1).

3.3.2 Which type of temporary accommodation will be available to the person?

Regarding the type of temporary accommodation that is available to a homeless person, the landfall of Hurricane Katrina in the USA in 2005 showed how private wealth, mobility, available infrastructure and public means can transform an entire country into a resource for temporary accommodation. Private means for travel expenses, a good travelling infrastructure, a high mobility with regard to both the spread of relatives and friends all over the country and the custom to travel made many of the affected leave their homes in order to stay with relatives or friends. At a later stage they rented flats, bought homes or took a hotel room somewhere away from their original home. All of them received housing assistance of the FEMA (Federal Emergency Management Agency) which in October 2005 was given to as many as 1.36 mio. homeless spread over all 50 states of the USA (see Figure 3.5)[15]. The overall cost of this programme for the 1.71 mio. applicants until 6.6.2006 was 5.89 billion US$ which points out the significance of the high public means of the state[16]. Although nearly half of the homeless (46.2%) applied for the help in a distance of less than 100 miles away from New Orleans it shows how the resources of usual homes of a whole country can contribute to shelter a large number of homeless and provide them with a proper adequate shelter while their homes are under reconstruction. However, this shall only be understood as an example in order to illustrate a sheltering option that usually is not associated with the temporary sheltering of homeless after natural disasters. In fact, it only represents one aspect of a much more complex and diverse sheltering situation. In spite of the large proportion of homeless being involved in this programme and its apparent benefits the overall sheltering situation after Hurricane Katrina like the whole coping mechanism has to be evaluated as insufficient given the wealth and possibilities of the affected country.

The given example of accommodating a large number of homeless in 'usual' flats underlines the before made statement that it is not possible to define a limit of a certain number of homeless above which the only feasible sheltering solution are tents. For sure in many other countries tents would have been the only possibility. But given the state of human development in the USA and the corresponding socio-economic conditions it was possible to provide 1.71 mio. homeless (Stand 2006-06-06) with financial aid, to allow them to rent some type of accommodation for a certain period. Therefore, the number of exposed can never be the deciding variable for the applicable sheltering solution but has always to be regarded together with the human vulnerability.

In contrast to the high mobility of the homeless in the USA after Katrina, the immobility of the affected of the earthquake in Pakistan in October 2005 characterised their sheltering needs. This immobility is not only owed to a lack of transport options but often to the need or wish of the homeless to stay at their original place. There are a couple of reasons which result from the living conditions of a mostly poor, agriculturally orientated population: many do not own the ground they cultivate and fear to lose it if they move away for some time as others might take the ground. Others need to look after their animals or want to stay close to their old home in order to retrieve their belongings from the rubble[17]. Hence, their situation is defined by low private wealth, social class and education. Due to the vast destruction public buildings with their potential function as shelters were no longer available, which was especially dramatic in the case of the destroyed schools, as many children lost their lives under the debris. Temporary accommodation with close-by living friends and relatives could as well be largely excluded[18]. Therefore, the fatal combination of an severe earthquake, a high structural vulnerability leading to extensive destruction and the need of local shelter created a great demand for tents with about 410 000 tents being delivered by beginning of December[19]. With regard to the cold climate, for sure they were not an appropriate solution but the supply of more sophisticated temporary shelters within a short period was not possible due to low public means and very bad conditions of the infrastructure which made transportation extremely difficult (see also Chapter 4.5).

3.3.3 How long will the person have to stay in the temporary accommodation?

An important factor for answering the question of how long a person will have to stay in temporary accommodation are the financial means for reconstruction. The Elbeflut in 2002 showed how large financial means combined with good resources for reconstruction can lead to a short stay in temporary accommodation. Immediate aid of 78.5 mio. € was given by the state and within months a large number of the 60 000 affected had received a compensation for their damages. The overall damage of 9.1 billion € could be covered thanks to a fund of the federal states and the Federal Republic of Germany of 7 billion €, financial means of the EU, donations and payments of insurances[20]. Together with the available resources for reconstruction such as initial pumping of flooded basements by the THW, waste collection of wet, unusable furniture, a capable building industry etc. the period in temporary accommodation was restricted to days or weeks.

Unlike the example of the Elbeflut two earthquakes in the Kerman province in Iran show how a lack of financial means can hamper reconstruction and elongate the stay in temporary accommodation. 14 month after the Bam earthquake of December 2003 the people still lived in containers and many had given up hope that they might ever return to normality. Although the Iranian government received large sums of foreign help and made plans for reconstruction, the affected never got any money. However, as they themselves had no financial means for the necessary reconstruction expenses they were dependent on getting long-term and low-interest credits in order to facilitate the reconstruction of their homes[21]. In the case of the second, less destructive earthquake in February 2005 in Zarand the Iranian government even did not apply for foreign help as it saw no need for it, although in the town of Zarand and some 40 surrounding villages over 10 000 families had been left homeless facing unusually harsh winter conditions[22]. The homeless were provided with tents and there were no signs that the support should be any different to the one in Bam so that – lacking private and public financial means – the people in Zarand faced a long period in temporary accommodation, too[23].

With regard to the available financial means for reconstruction it shall be noted that large public means do not necessarily mean that a lot of money will be available for reconstruction as this highly depends on the priority with which public means are spent. As an example of the priority of spending money it might be returned to the situation in the USA after Hurricane Katrina. In March 2006, six month after the landfall of Katrina, the reopening of only 18 out of 117 public schools in New Orleans had been achieved while large amounts of money were spent e.g. on the war in Iraq (81 billion US$ in 2005 [24]). Beside demonstrating that the existence of financial means will not necessarily result in a fast reconstruction as the effort in succeeding in it might vary largely, the post-Katrina situation shows how one very specific sector of reconstruction can become the determinant variable for the duration of stay in temporary accommodation in highly developed countries: as schools did not reopen rapidly families with children – regardless the situation of the reconstruction of homes – could not return to New Orleans which meant a continuation of the stay in temporary accommodation[25].

Finally the South-East Asia tsunami of 2004 can be used as an example to demonstrate how the resources for reconstruction can become the determinant factor for the duration in temporary accommodation. While the estimated cost for reconstruction of 10 billion US$ was more than covered by the 13.6 billion US$ of agreed help, a fast reconstruction was obstructed by limited resources, e.g. the availability of labour, logistical problems and policy challenges. Therefore, one year after the disaster 78 000 people in Aceh and Nias still lived in tents and hundreds of thousands more across the region stayed in barracks or with host families[26].

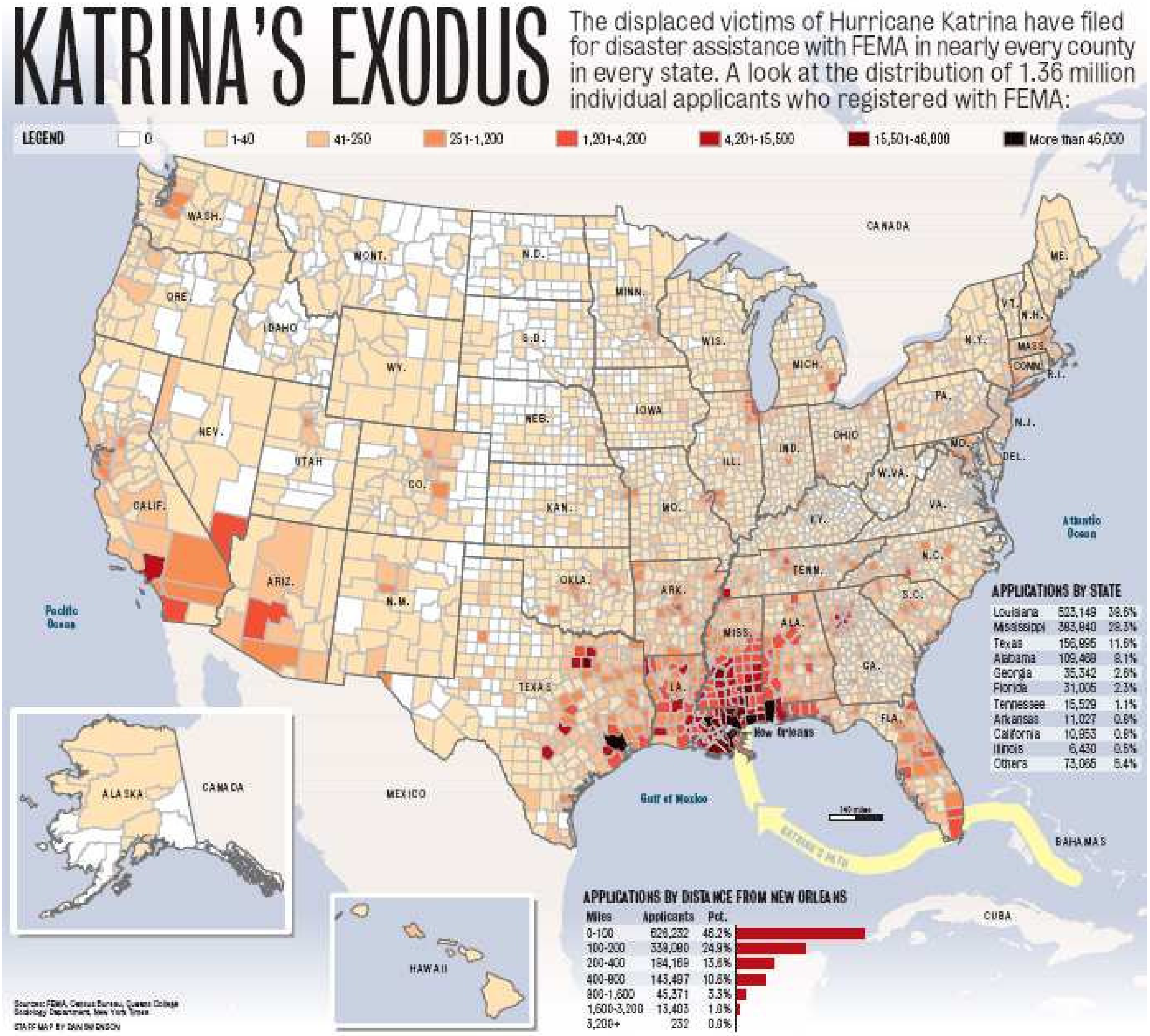


Figure 3.5: Spread of homeless of Hurricane Katrina over the USA [The Times-Picayune, 2005]

Notes

[1]EM-DAT (2005a)
[2]USAID (1997)
[3]DKKV (2003)
[4]ICRC (1997)
[5]Voice of America (VOA) (1997)
[6]ICRC (1998)
[7]Bayerisches Rotes Kreuz (BRK) KV Nürnberger Land (2006)
[8]Feuerwehr Herzogenaurach (2006)
[9]Somalia Aid Coordination Body (SACB) (1998)
[10]USAID (1997)
[11]UN Office of the Special Envoy for Tsunami Recovery (2006)
[12]IFRC (2003)
[13]WFP (2004)
[14]Habitat for Humanity International (2005); Habitat for Humanity International (2006)
[15]The Times-Picayune (2005), p. A-18
[16]FEMA (2006)
[17]Pro Vention Consortium, ALNAP (2006), p. 5; IFRC (2005)
[18]ACTED (Agency for Technical Cooperation and Development) (2006)
[19]Emergency Shelter Cluster, South Asia Earthquake, Pakistan (2005), p. 1
[20]Berliner Morgenpost (2003)
[21]Farshid Motahari, DPA (2005)
[22]UNHCR (2005)
[23]Operation Mercy (2005)
[24]Jonathan Weisman, Washington Post (2006), p. A01
[25]The Bookings Institution (2006), p. 56
[26]UN Office of the Special Envoy for Tsunami Recovery (2006)

Chapter 4

Need for Shelter Aid

4.1 Introduction

Having analysed on a very general level the risk of becoming homeless due to natural disasters and the various options for post-disaster shelter, the work will now move on to focusing on one specific post-disaster shelter situation, i.e. tents as emergency shelters in cold climates. This implies not only focusing on a specific structure for shelter but as well on a specific socio-economic context, which was identified in Chapter 3 as the one of highly vulnerable, low or medium developed countries. It is important to highlight this socio-economic context, as only with it in mind the existing shelter solutions can be understood and a reasonable further development is possible. Before moving on to specific shelter solutions, however it is useful to keep the general viewpoint a bit longer and to raise the question what functions a shelter has to fulfil. By this a sensitisation for the minimum requirements of adequate and humane shelter shall be gained. Moving on to specific shelter solutions, these requirements shall form a measure of what we are responsible to achieve even though the specific socio-economic and disaster situations will obstacle this.

Additionally, in a later part the chapter will motivate the focus on tents as emergency shelters for cold climates by referring to various cold climate natural disasters in order to demonstrate their significance both for the frequency of occurrence and for the existing deficits in the provided shelter aid. The emergency shelter situation after the Pakistan earthquake of October 2005 will be analysed in detail forming the major point of reference for the undertaken development of emergency shelters as it, unfortunately, has to be seen as an exclamation mark for the unmet shelter aid needs in cold climate regions.

4.2 The Right to Adequate Shelter

Universal Declaration of Human Rights, Article 25:

> 'Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, ***housing*** and medical care and necessary social services, ...'[1]

Nevertheless the compliance of the right to adequate housing seems fairly self-evident in the European context, it unfortunately is not true in many parts of the earth. The declaration as a human right emphasises the ultimate importance for each individual and the need to progress towards the achievement of adequate housing for as many people as possible even in the adverse conditions of post-disaster sheltering.

4.3 Functions of Shelter

The Universal Declaration of Human Rights raises the question what adequate housing means or in other words which functions a shelter has to fulfil. Within the aid community this question has been dealt with in numerous definitions by all major organisations of which the one by the UNDP/UNHCR (United Nations High Commissioner for Refugees) shall be cited here as an example of the often very similar formulations:

> 'Shelter must as a minimum provide:
>
> protection from the elements
>
> space to live, rest and store belongings
>
> privacy and emotional security.'[2]

It can be observed that over the last years the definition of the functions of shelter has changed from the mere restriction upon the sheltering aspect as represented in the definition above towards a perception of the possible and necessary interaction of shelter with the surrounding. This has led to the integration of the livelihood and settlement aspects associated with shelter, so that three major functions of shelter can be defined:

1. Sheltering
2. Livelihood
3. Settlement

SHELTERING FUNCTIONS	⇒	DESIGN	
		Specification	Influenced by
• protection against cold, heat, wind, rain, snow		variable	climate
• protection against vectors and pests		variable	vectors/pests
• storage of belongings		invariable	—
• privacy and emotional security		invariable	—
• place for family life including basic tasks as cooking, washing		variable	climate

Table 4.1: Sheltering functions and their influence on the requirements for design

The second and third point clearly have to be seen as an extension beyond the basic (survival) need for shelter but nevertheless can not be neglected. Even though in the emergency shelter context the satisfaction of basic shelter needs dominates, the often long duration of the emergency shelter phase necessitates the incorporation of livelihood aspects (i.e. the possibility to generate a family income) and settlement aspects (i.e. the location of the shelter in an appropriate community) in order to facilitate a long term recovery of the affected.

Subsequently, for each listed aspect the functions will be worked out in detail, showing in tabular form how they inform either the required design or location of the shelter[3]. Whereas in the given context of providing adequate emergency shelters the interest in a derivation of the design from the necessary functions of a shelter is straightforward, the significance of location only becomes apparent making one step further: The settlement functions will demonstrate that from the requirement of self-selected locations (i.e. the affected's option to chose by himself the location of his shelter) finally design requirements arise i.e. the ease to transport and construct the shelter. As for emergency shelters a fast delivery is needed, Table 4.1 specifies for the sheltering functions whether a function leads to a variable or invariable design specification and hence to the possibility of a fast deliverable standard design. Regarding the variable specifications it can be seen that first of all the climate necessitates different designs. As the sheltering functions represent the very basic shelter need and therefore have to be fulfilled in any case, the necessity to provide a standard shelter with possible additions for different climates e.g. a winterisation kit has to be derived from Table 4.1. In the same manner a protection against vectors and pests is possible by additions e.g. by mosquito nets. Therefore, having dealt with all variable specifications, it can be concluded that the basic need for shelter represented by the sheltering functions can be satisfied by a standard tent with appropriate additions to hand. This conforms with the UNHCR/UNDP statement that the very basic shelter need is usually uniform[4].

Having a closer look at the livelihood functions in Table 4.2 it can be noted that the functions influencing the design brake up the before presented uniformity by more diverse

LIVELIHOOD FUNCTIONS	⇒	**DESIGN**	/	**LOCATION**
• place for work		×		
• storage of goods/tools		×		
• shelter for animals		×		
• land availability and access to cultivation and grazing				×
• location and access to market areas				×
• within commuting distance to employment				×
• availability of and access to local services essential for particular economic activities				×

Table 4.2: Livelihood functions and their influence on the requirements for design or location

SETTLEMENT FUNCTIONS	⇒	**LOCATION**	⇒	**DESIGN**
• address for receipt of services • maintenance of social contacts • starting point for further action • establishment of territorial claims	⇒	self-selected	⇒	ease to transport and construct

Table 4.3: Settlement functions and their influence on the requirements for location and design

requirements. As the need for access to livelihood is not as immediate and pressing as the pure sheltering need, it seems however feasible to account for it within a standard design approach by later on selected and delivered additions like tarpaulins, corrugated galvanised iron sheets and timber pole to construct simple shelters for animals, tools or basic workshops. For the functions influencing the location the same progress as shown in Table 4.3 leading from a location requirement to a design requirement applies.

Table 4.3 finally shows for the settlement functions the importance of a self-selected location of the emergency shelter. Being able to carry a tent to the own village of origin allows to stay within the security giving surrounding of the family and neighbourhood, to use existing social networks etc. and therefore facilitates a faster mental and economic recovery. It necessitates from the design point of view a tent that can be transported in the worst case by foot and constructed without external help. Given the wide usefulness of this two design parameters a standard design should incorporate them as well.

The above given functions are summarised graphically in Figure 4.1 which additionally indicates the direction of the functions as either acting on the shelter (arrow towards tent), starting from the shelter (arrow away from tent) or actions within the shelter (arrow within tent).

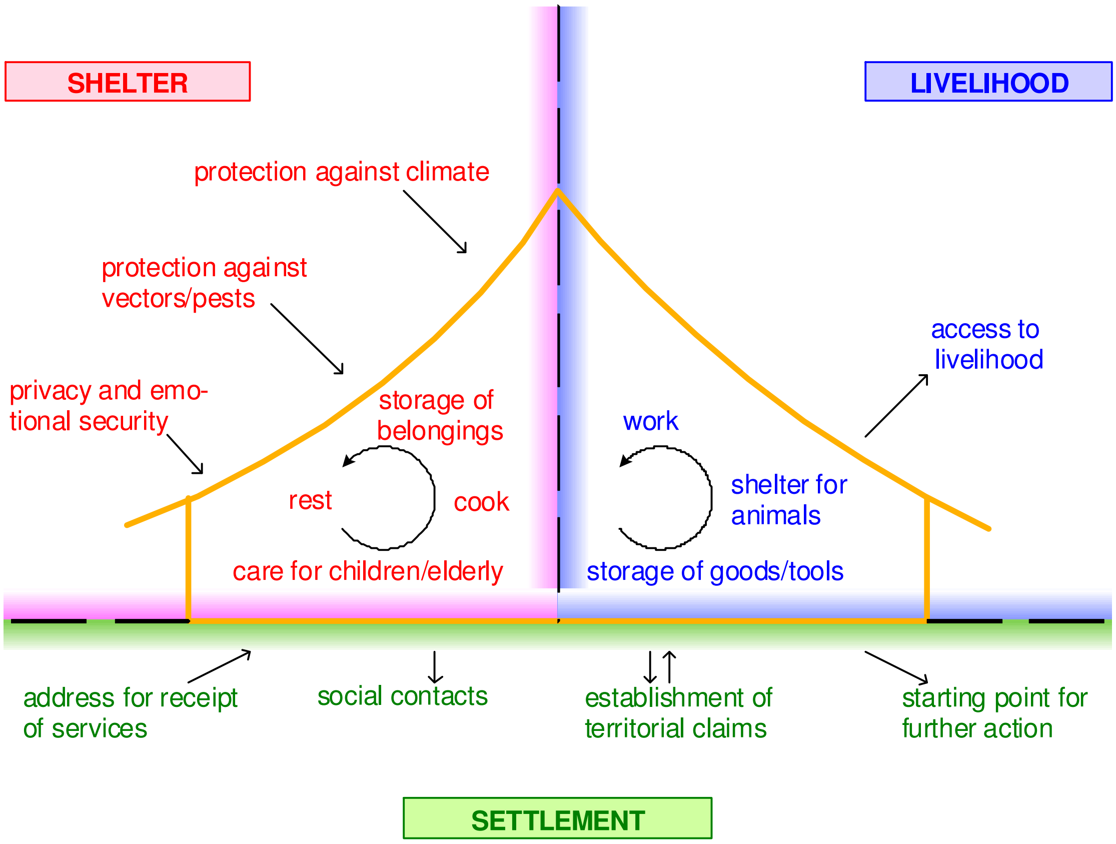


Figure 4.1: Functions of shelter

4.4 Disasters in Cold Climate Regions

One of the central, previously presented functions of shelter is the protection against the climate. In cold climate regions this can become eminently critical given the scarce availability of sheltering material and transport capacity in the aftermath of natural disasters. In combination with the restricted options for emergency shelters under certain socio-economic conditions (see Chapter 3) this can result in the use of tents as the only available emergency shelter option. Hence, in spite of the apparent shortcomings with respect to the protecting function in cold climates, natural disasters cause a demand for tents suitable for cold regions, the so called winterised tents (see Figure 4.2).

To illustrate this demand it was opted to have a closer look at earthquakes as one type of homelessness generating natural disasters. Table 4.4 gives a collection of a couple of severe earthquakes in cold regions and the evoked number of homeless. Clearly the most renowned and severe is the Pakistan earthquake of October 2005 with 3.5 mio. homeless. However, in spite of the relative unrenownedness, disasters like the Zarand

Figure 4.2: Collapsed tent in Balakot after Pakistan earthquake [Tanoli, 2006]

Date	**Location**	**Country**	**No. of homeless**[5]
1983-10-30	East Anatoly	Turkey	33 000
1988-12-07	Spitak	Armenia	530 000
1999-11-12	Düzce-Bolu	Turkey	55 000
2003-12-26	Bam	Iran	45 000
2005-02-22	Zarand	Iran	families: > 10 000
2005-10-08	Muzaffarabad	Pakistan	3.5 mio.

Table 4.4: Earthquakes in cold regions with need for winterised tents

earthquake should not be ignored.

As for all listed earthquakes tents were the predominant emergency shelter option this selection of disasters strongly underlines the demand for winterised tents. The therefrom arising necessity to improve the winterisation of emergency shelter tents will become apparent by the subsequent discussion of the emergency shelter response in cold climate disasters. For this purpose it shall be referred to the following chapter which will deal with the response after the Pakistan earthquake. Furthermore, Chapter 5.4 will investigate the response after the Düzce-Bolu earthquake and give detailed insight into the standard of tents delivered to cold climate regions.

Widening the view from the examples of past disasters to the general risk of homelessness in cold climate regions and the subsequent demand for winterised tents, a comparison between the world map of earthquake hazard (Figure 4.3) which indicates a wide distribution of earthquake endangerment and the worldwide minimum temperatures during winter is helpful. Figure 4.4 gives for winter conditions on the northern hemisphere the mean temperature in January. The vastly spread bluish colors represent temperatures below 0 $°C$ and consequently identify a large potential demand for win-

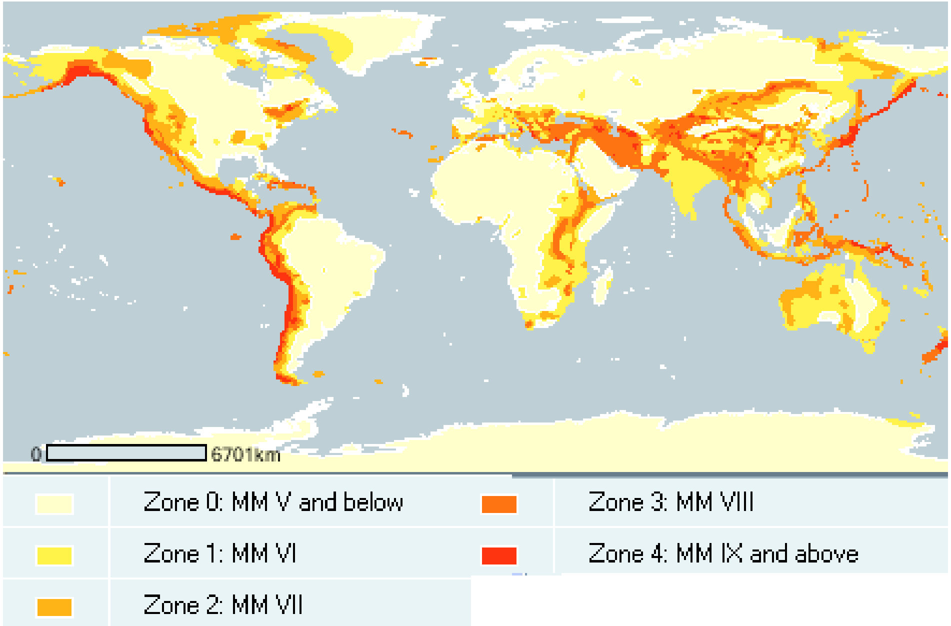


Figure 4.3: World map of earthquake hazard [Munich Re, 2008]

terised tents. In contrast, the winter conditions on the southern hemisphere are much milder which was the reason for depicting here the mean of the lowest temperature in July. It can be observed from Figure 4.5 that the area with bluish colors and hence with a potential demand for winterised tents is limited to small parts of the southern hemisphere. It can be concluded that large areas with both an earthquake endangerment and low winter temperatures exist which identifies a significant potential demand for winterised tents.

4.5 The Pakistan Earthquake, 8 October 2005

4.5.1 Introduction

The severe Pakistan earthquake of October 2005 led to a massive devastation in a mountainous region with harsh winter conditions. With winter approaching, immediately a pressing need to shelter hundreds of thousands in tented camps arose (see Figure 4.6). With no proper winterisation concept to hand, the provided emergency aid clearly indicated the lack of sufficiently winterised tents and pointed out the need for further developments. The following detailed analysis of the post-disaster shelter situation will therefore serve as an investigation of the available solutions and their shortcomings as well as motivate the subsequent subject of this work.

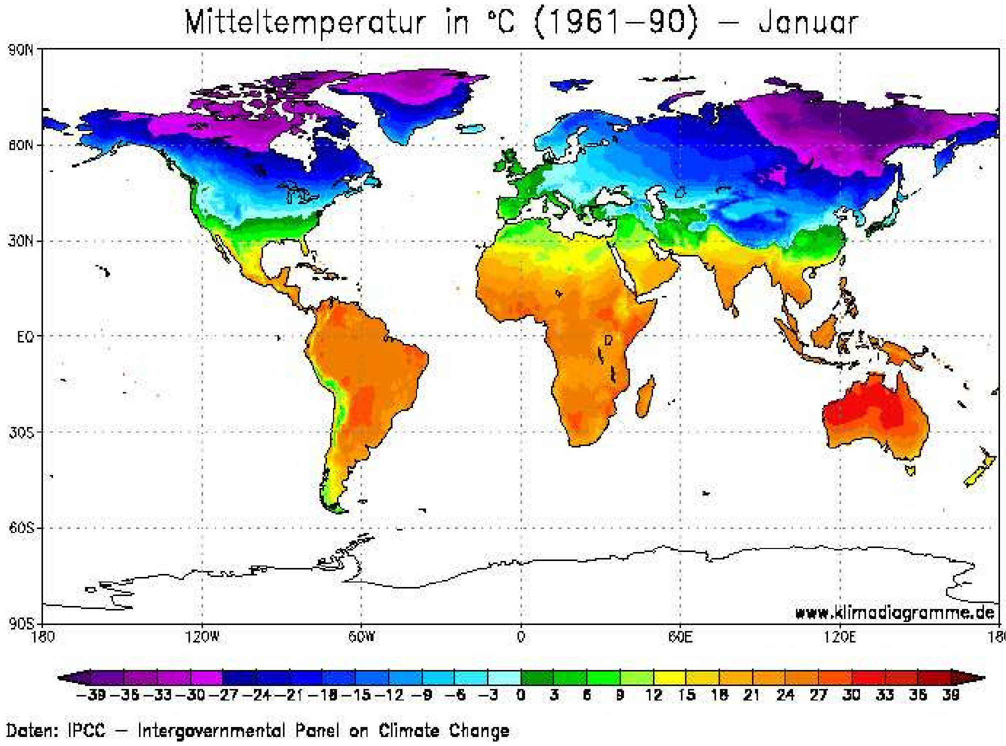


Figure 4.4: Winter on northern hemisphere: mean temperature in January [Klimadiagramme.de, 2006]

4.5.2 Disaster Situation

On 8 October 2005 a massive earthquake of 7.6 Richter scale magnitude struck Northern Pakistan causing severe damage in a huge area comparable in size to Belgium (see Figure 4.7). While the predominant destruction occurred in Pakistan the north of India was also hit, which explains the denomination as South Asia earthquake in a number of publications. Due to the extend of devastation this work will only deal with the situation in Pakistan. There, it is estimated that the earthquake killed 86 000 people, injured more than 128 000 and left about 3.5 mio. homeless. About 600 000 homes were severely damaged or destroyed and about 1.1 mio. people lost their livelihoods (see Figure 4.8)[6]. In view of the enormous number of people in need of shelter assistance and the very limited time available until the onset of winter in mid December, the provision of emergency shelter aid was a very challenging task. It was additionally hampered by the mountainous area, blocked roads and the location of villages which were often widely spread and far of the nearest road, requiring hours of walking up steep mountains[7]. Given the harsh winter conditions, personal insulation was of major concern requiring winter clothing, thick blankets for sleeping, water proofing of tent roofs and

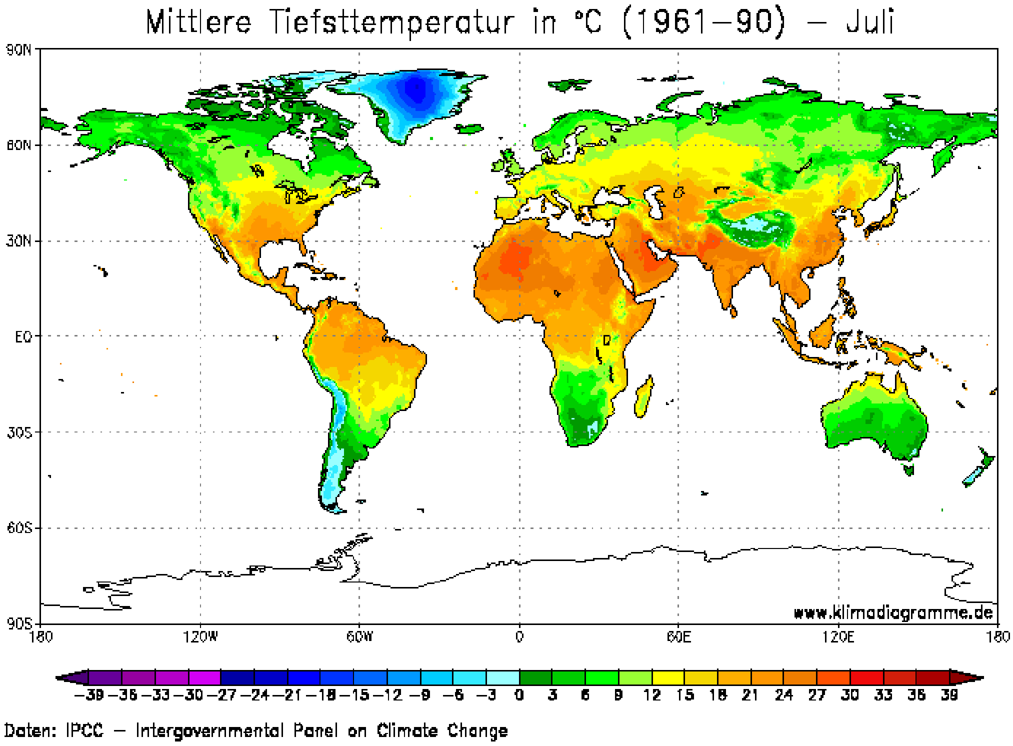


Figure 4.5: Winter on southern hemisphere: mean of lowest temperature in July [Klimadiagramme.de, 2006]

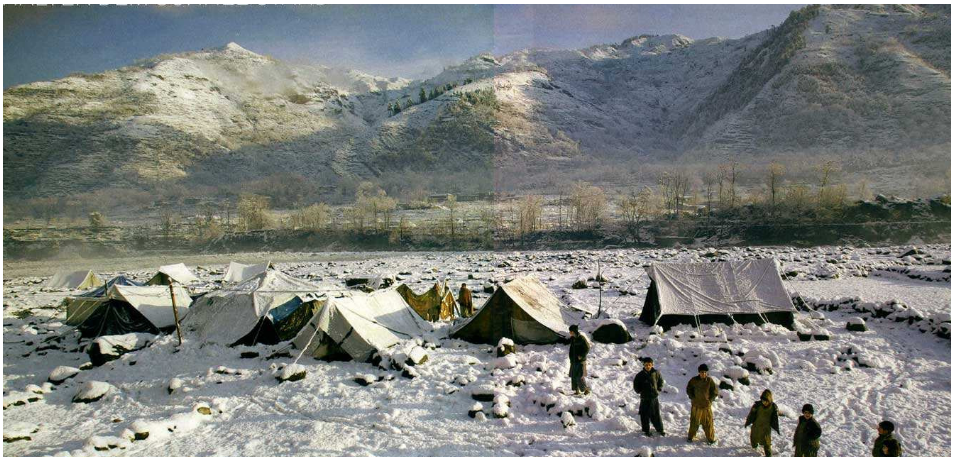


Figure 4.6: Self-settled camp in Allai Region [Gassel, 2006]

Figure 4.7: Location of earthquake epicenter in Northern Pakistan [Pakistan Earthquake 2005, 2008]

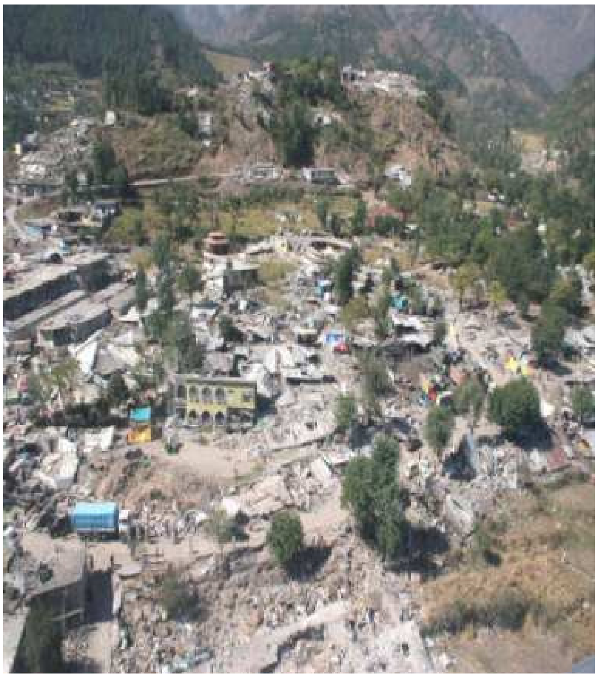


Figure 4.8: Earthquake devastation in Manshera Town [United Nations Camp Management Cluster, 2006]

floors as well as a floor insulation in order to prevent excessive heat loss from persons sitting or sleeping on the ground. Consequently, shelter was given the first priority in the Government of Pakistan's Emergency Plan[8].

Figure 4.9 gives an overview of the area hit and the number of affected. The provided data is split into regions, the so called tehsils. The included table gives for each tehsil the percentage of the totally required tents as delivered by 11 November. It clearly indicates the unmet shelter need 5 weeks after the disaster. At the same time the funding for the emergency phase was of large concern as only 128.6 mio. $ of the 550 mio. $ appealed for by the UN had been committed and it was feared that the progress of aid could be significantly hampered[9]. However, the situation changed after the donor's conference of 19 November were the commitments and pledges made even surpassed the amount appealed for[10].

4.5.3 Climatic Conditions

The climate in the disaster region is characterised by the mountainous location with parts of the affected areas laying above 5 000 ft. It is estimated that 400 000 aid-dependent people lived in the highland zone (5 000 - 7 000 ft)[11]. The climatic data offered by UN-OSAT, an organisation providing satellite imagery and related geographic information to UN humanitarian and development agencies and their implementing partners, shows for the beginning of January 2006 in some affected regions land surface temperatures (LST) at night below $-20\ °C$ and a snow cover of up to 100 cm (see Appendix B, Figure B.1 and B.2).

4.5.4 Winter Race

In order to supply all affected with 'one warm room' (Federal Relief Commission (FRC) policy[12]) and to avoid post-disaster morbidity and mortality soon after the earthquake the so called 'winter race' started, following literally a top-down strategy, i.e. starting with the aid in high locations and then moving downwards[13]. The first cases of hypothermia and death due to cold already by mid-November underline the necessity of the winter race which successfully prevented significant excess mortality[14]. Because of the extremely cold weather and the heavy snowfalls it was opted to provide homeless in locations above 5 000 ft with shelter kits allowing for the construction of makeshift shelters or other temporary shelters rather than tents. A fast delivery of aid to high locations was further urged by the worsening transport situation due to the onset of winter with no flights possible at a large proportion of days and tertiary roads blocked[15]. By 6 December the overall coverage in locations above 5 000 ft was assumed to be over 90 % [16].

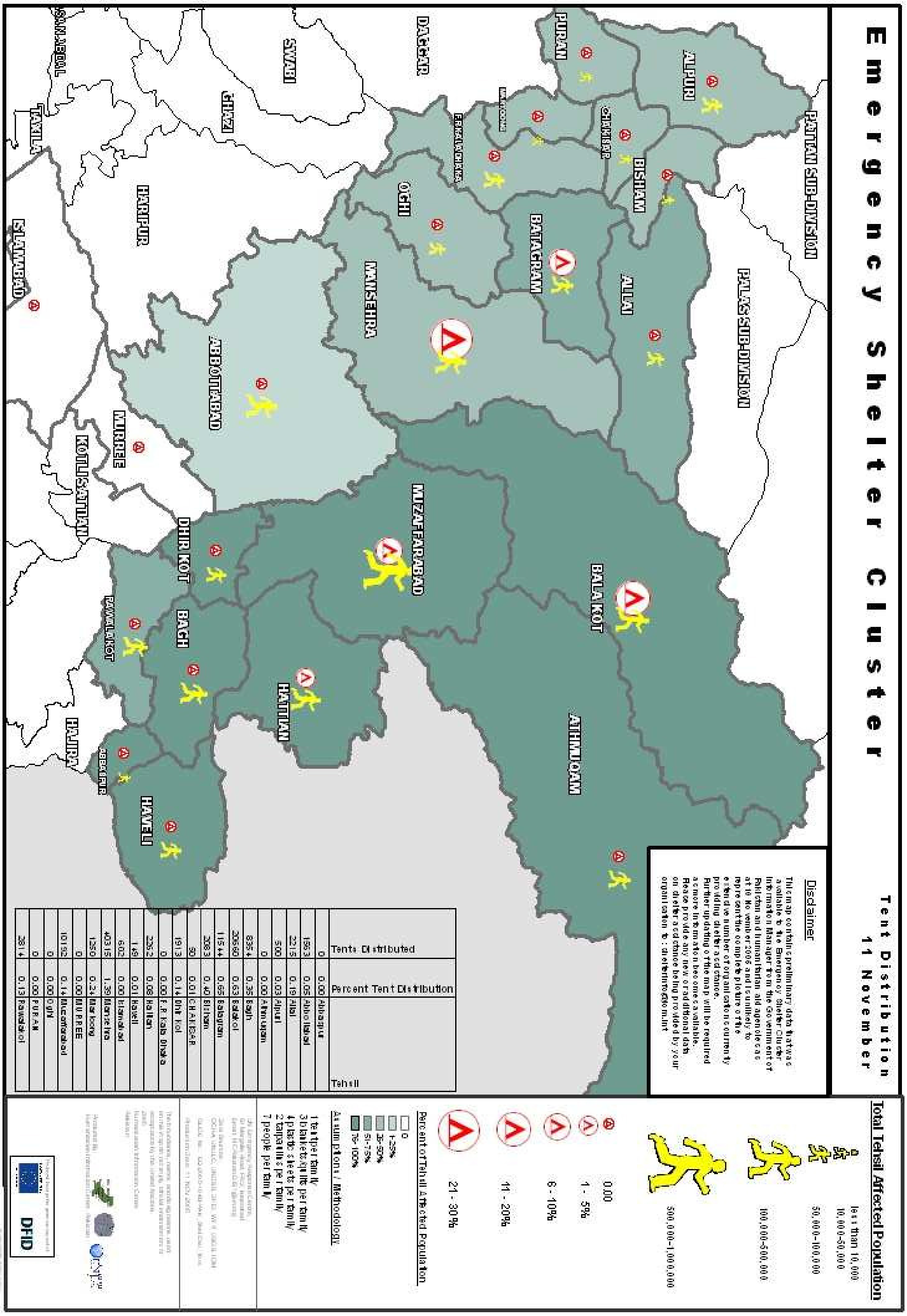


Figure 4.9: Affected population and tent distribution as by 11 November 2005 [Relief Web, 2005]

4.5.5 Winterisation Campaign for Non-winterised Tents

The supply situation with tents was characterised by a wide variety of shapes and sizes that could be found in the tented camps[17]. In spite of the extremely cold conditions, 85 - 90 % of them were not winterised[18]. This necessitated improvements which were carried through by a winterisation campagain initiated by the UNHCR in its function as head of the camp management cluster[19]. The winterisation consisted of 3 blankets per person plus 4 mattresses, 2 plastic sheetings and a stove per tent. The plastic sheeting was deployed to cover the roof and the floor[20]. As a number of tents do not have vertical walls but only a structure which can be denominated as a roof, hereafter the term roof will always refer to the entire structure (roof and eventually walls) which delimitates the inside of the tent from the surrounding air. Blankets of minor quality which did not fulfil the requirments for sleeping were nevertheless useful as they could serve as an additional internal tent insulation[21]. In contrast to a basic winterisation, consisting only of additional plastic sheeting and 3 blankets per person, the before described winterisation package will hereafter be termed as advanced winterisation[22]. However, the numbers of delivered relief items indicate that entire packages can only have been available to a small proportion of the occupants of the about 410 000 tents[23]: Within 120 days after the disaster (6 February 2006) the UNHCR as lead of the camp mangement cluster had provided only 6 000 mattresses (as compared to 500 000 blankets), while until 6 December 2005 all agencies together had delivered over 3 mio. blankets (28 % coverage) and 17 600 stoves (10 % coverage)[24]. It shall be annotated that, in spite of the eminent risk of tent fires and potential deaths, the freezing temperatures lead to the provision of stoves to individual tents. Given the large demand for fire wood for heating tents or temporary shelters in combination with the timber required for reconstruction a negative impact on the environment by the unsustainable exploitation of resources and subsequent landslides was feared[25].

4.5.6 Shelter Situation 2 Months after the Earthquake

Two month after the disaster, on 10 December 2005 the shelter situation was as follows: 35 000 self-help shelter kits had been distributed consisting of corrugated galvanised iron (CGI) sheets for roofing, plastic sheeting, hammers, nails, spades, pickaxes, saws, stoves, blankets, mattresses, kitchen sets and children's clothing (see Figure 4.10)[26]. They enabled affected families to build temporary shelters using whatever material was rescuable from their destroyed homes. A total of more than 5 mio. CGI sheets were distributed until May 2006 [27]. It shall be noted that these kits were not only distributed because of their superior performance compared to tents but as well due to the fact that not enough tents were available[28]. In addition to the shelter kits 30 000 transitional shelters had been provided by the Pakistan military, summing up to a minimum of 595 000 people living in non-tent shelters. 170 000 people were living in planned tented

Figure 4.10: Distribution of self-help shelter kits [International Aid + Trade, 2007]

camps[29] while the large majority of 1.9 mio. affected lived in 271 500 tents in self-settled camps or in the vicinity of their former homes (see Figure 4.11 and 4.12). The large number of affected living in self-settled camps is a result of the scarce availability of planned camps in the weeks after the disaster[30]. The remaining portion of the 3.5 mio. homeless had either migrated to lower elevations or to further away host families[31].

4.5.7 Temporary Shelters

In addition to the above mentioned self-help shelter kits and temporary shelters of the Pakistan military a number of similar types of shelter were deployed, of which two examples shall be dealt with in this chapter. Based on a traditional, local type of simple shelter the construction of one-room Bandi houses was supported. Bandi houses are excavated into the ground and have a tin roof resting on 1 m high stone walls[32]. Another locally deployed option were houses of a wooden frame structure and CGI sheeting of which the Kinderhilfe Afghanistan (German Aid for Afghan Children) constructed 1 300 units (see Figure 4.13)[33].

4.5.8 Living Conditions in Tented Camps

As a consequence of heavy rains, the living conditions in tented camps were worsened by wet and muddy conditions or even local flooding (see Figure 4.14)[34]. In the first week of January 2006 heavy snow and rainfalls let 40 - 50 % of the non-winterised tents collapse which thereafter had to be re-erected. As the collapses were caused by inproper tent erection and people not clearing of the snow from the roofs, it was assumed that learning from mistakes these problems would thereafter be overcome[35].

Figure 4.11: Planned camp in Muzaffarabad [United Nations Camp Management Cluster, 2006]

4.5.9 Shelter Aid in Remote and High Locations

Due to the remote location high up in the mountains with extremely hard winters and difficult supply with relief goods a significant number of affected left their villages and relocated to camps in lower locations[36]. However, the feared excessive migration was avoided by the winter race, reducing the accompanying negative effects of a higher dependence on external help with all personal resources left behind as well as of a slowed down reconstruction. An additional pull factor for the stay was, that many families did not want to leave their land as they did not own it and feared it might not be available upon their return home[37]. Furthermore, a migration would have destroyed the option to salvage belongings from the ruins of their houses[38].

The supply to remote and high locations was characterised by extreme difficulties which often necessitated the delivery by helicopters as no road access was available[39]. Frequently tents had to be transported from general distribution points up to remote villages by mule or by the affected themselves (see Figure 4.15)[40].

4.5.10 Floor Insulation of Tents

A survey of tents outside planned camps below 5 000 ft at the beginning of December 2005 revealed that still three quarters of the tents did not even feature a floor insulation by a tarpaulin (see Figure 4.16)[41]. In those cases, where an improved floor insulation could be found, solutions like the subsequently presented ones were deployed: The aid agency Oxfam distributed 3 - 4 mm thick mats of artificial straw[42]. Furthermore, local solutions were carried through by the affected themselves like erecting their tents on top of mounds of hay[43]. Based on the people's experiences of surviving extremely cold

Figure 4.12: Self-settled camp in Muzaffarabad [United Nations Camp Management Cluster, 2006]

Figure 4.13: House of CGI sheeting for two families (7 m x 4 m x 2.2 m) [Kinderhilfe Afghanistan, 2006]

winters, they also created a multi-layered solution integrating both previously mentioned solutions: Raising the earth underneath the tent above the level of the surrounding area, the earth was then covered by a layer of hay or cut grass, followed by plastic sheeting, mats of artificial straw and topped by rugs or quilts[44]. Another four-ply floor option is shown in the photographs of Figure 4.17 substituting the natural insulation of hay or grass by some plastic material and the plastic straw mats by similar plastic prayer mats. Among people migrating from the mountains another, traditional option for an insulated and drained floor was observed: the downmost layer consisted of stones, rubble or bricks with spaces in between which were filled by pine needles or hay, topped by further pine needles or hay and finished by a plastic prayer mat or tarpaulin as shown in Figure 4.18 [45].

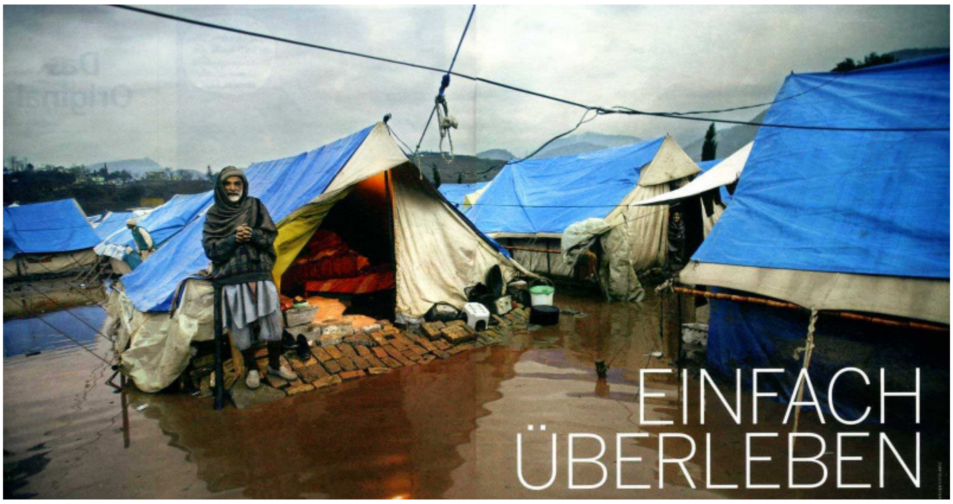


Figure 4.14: Flooded camp [Gassel, 2006]

4.5.11 Situation after the Winter 05/06

At the end of the winter 05/06 the reconstruction of homes started and tented camps were closed down by April 2006. However, due to the slow progress of reconstruction many people had to return to tented camps for a second winter. As the Government of Pakistan gave only short-term notice of the necessity to reopen camps, the aid agencies faced a second time the problem of providing in a short period of time shelters adequate for the harsh winter conditions[46].

Figure 4.15: Tent transport from distribution point in Jabra up to remote mountain village [IFRC, 2005]

Notes

[1]United Nations General Assembly (1948)
[2]UNDP (2000), p. 31
[3]The named functions were adapted from UNDRO (1982), p. 8 and OCHA (2006), p. 53
[4]UNDP (2000), p. 31
[5]Source of homelessness data:

East Anatoly, Spitak, Düzce-Bolu, Bam earthquake: EM-DAT (2008)

Zarand earthquake: Operation Mercy (2005)

Muzaffarabad earthquake: IFRC (2005a), p. 2

[6]IFRC (2005a), p. 2.; ERRA and IASC Country Team (2006), p. 3
[7]Catholic Relief Services (CRS) (2006)
[8]Shelter Cluster Islamabad (2005), p. 1
[9]Oxfam (2005), p. 4
[10]IFRC (2005a), p. 2
[11]Emergency Shelter Cluster (2005), p. 1
[12]The Federal Relief Commission was initiated after the Pakistan earthquake in October 2005 with the mandate to plan, coordinate, direct and monitor all relief efforts. All Government Agencies including Armed Forces concerned with the relief efforts should function through FRC.
[13]OCHA (2005)
[14]Emergency Shelter Cluster, South Asia Earthquake, Pakistan, Technical Unit (2005), p. 1; ERRA and IASC Country Team (2006), p. 5
[15]OCHA (2005a)
[16]Emergency Shelter Cluster, South Asia Earthquake, Pakistan (2005), p. 1
[17]Oxfam America (2005)

Figure 4.16: Tent pitched on wet concrete slap with floor insulation of cardboard and 'old clothes' [Crawford, 2005]

Figure 4.17: Four-ply floor insulation of tarpaulin, plastic insulation material, plastic prayer mat and rugs (not shown) [Crawford, 2005]

[18]USAID (2005); Emergency Shelter Cluster, South Asia Earthquake, Pakistan (2005), p. 1

[19]The Humanitarian Cluster Approach was first deployed after the Pakistan earthquake. It signifies that all relief actions are split in certain sectors, the so called clusters, which are coordinated by the assigned leading agency.

[20]UNHCR (2006)

[21]Emergency Shelter Cluster, South Asia Earthquake, Pakistan (2005), p. 3

[22]Emergency Shelter Cluster, South Asia Earthquake, Pakistan, Technical Unit (2005), p. 5

[23]FRC figures show 510 000 tents.

[24]UNHCR (2006a); Emergency Shelter Cluster, South Asia Earthquake, Pakistan (2005), p. 1

[25]OCHA (2005a)

[26]OCHA (2005b)

[27]ERRA and IASC Country Team (2006), p. 5

[28]Shelter Cluster Islamabad (2005), p. 1

[29]Planned tented camp signifies that the camp has been planned and subsequently run by an aid agency. In contrast to this a self-settled camp evolves in a location selected by the affected themselves

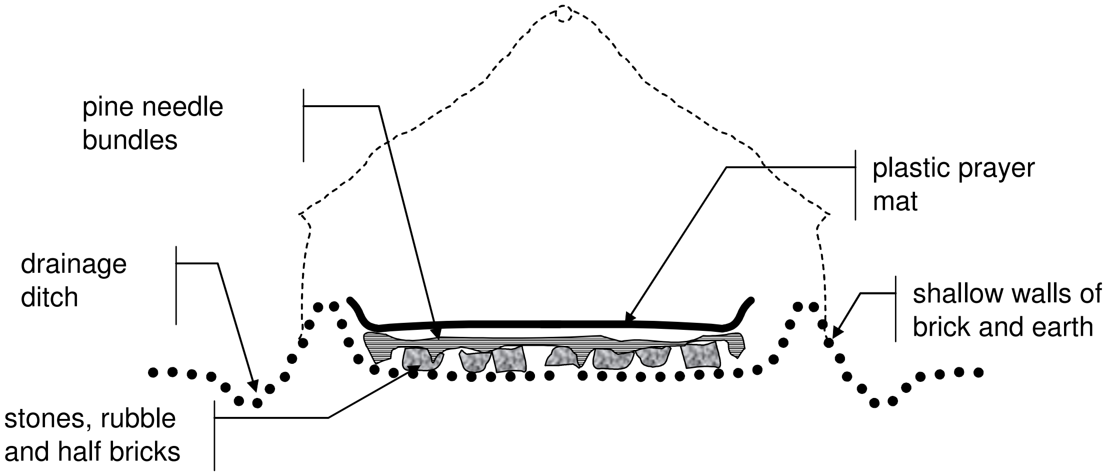


Figure 4.18: Floor insulation of stones, pine needles and plastic prayer mat [Crawford, 2005]

for pitching up their tents.

30Oxfam (2005), p. 2

31Emergency Shelter Cluster, South Asia Earthquake, Pakistan (2005), p. 5

32Oxfam (2005a)

33Kinderhilfe Afghanistan (2006)

34OCHA (2006a)

35OCHA (2006b)

36USAID (2005)

37Pro Vention Consortium, ALNAP (2006), p. 5

38IFRC (2005)

39OCHA (2005c), p. 3

40IFRC (2005)

41OCHA (2005)

42Oxfam (2005a)

43Oxfam America (2005)

44Oxfam (2005b)

45Crawford (2005)

46Caritas International (2006)

Chapter 5

Tents for Personal Shelter

5.1 Introduction

The following chapter will deal with different types of tents serving as personal shelters and allow the reader to get an overview about existing structures and their properties. The attention will not be limited to tents for humanitarian aid but widen the view upon other fields i.e. tents for camping/polar expeditions and nomad tents. As the function of these tents is very similar to those used for humanitarian aid, it shall be investigated whether they can inform the improvement of disaster relief tents. In difference to the previous chapters the focus here will be no longer on the process of sheltering persons in improving types of structures but on the structure itself. To highlight this change in perception of one and the same objective the denomination will consequently move from emergency shelter (function) to tent (structure). This has the additional benefit to allow for a consistent denomination of the various tent-based shelters discussed in this chapter. Due to the focus of the thesis on tents for cold climates a first subchapter on family tents for humanitarian aid in general will be followed by one specifically on family tents in cold climates. Together with the presented case study of an earthquake in a cold region this will contribute to getting a good overview about the special features of the cold climate tents deployed so far.

5.2 Family Tents for Humanitarian Aid

Family tents for humanitarian aid means tents which are employed in humanitarian aid to house an entire family. As in the context of this work the application of the family tents for humanitarian aid is obvious, hereafter these structures will be in short addressed as family tents.

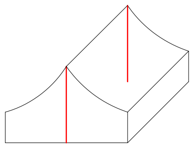
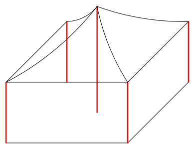
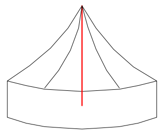
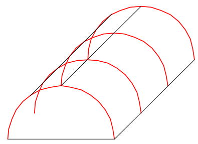
5.2.1 Standards of Family Tents for Humanitarian Aid

Other than in many other fields no uniform standards for shelter aid exist. This can be explained partly by the large number of various players e.g. governments, UN agencies, NGOs (Non-Governmental Organisations) involved in providing humanitarian aid and their very different aims and objectives. However, another important role plays the long lasting neglect ion of the sector which, in comparison to other aid sectors such as medical aid, has led to a retarded development of the sector and corresponding standards. When in 2000 the Sphere Project was launched, it introduced minimum standards in disaster response considering as well the shelter sector[1]. Even though these standards have to be understood in a literal meaning as the real minimum of what should be delivered to the affected, these standards are often not fulfilled by the tent specifications of the aid agencies. For example many tents do not provide the required 3.5 m^2 of covered floor area per person[2]. Additionally, past disasters showed that beside the Sphere Standards further specifications are necessary to guarantee adequate and consistent shelter aid. To push on the evidently needed development, in 2006 the Shelter Module was initiated by the Shelter Centre[3] with the aim to bring together all important players of the humanitarian community and finally achieve a consensus upon standards and corresponding indicators. As the work was only recently started and is due for finalisation in 2011, so far only preliminary results exist[4]. In the end, however, it is hoped that the standards will enable the development of better family tents and a more consistent shelter aid.

5.2.2 Types of Family Tents for Humanitarian Aid

With the different aims and objectives of the various providers of humanitarian aid in mind, it is apparent that a wide range of different tent types for humanitarian aid exists. Table 5.1 offers an overview about the four main types, their characteristics and the agencies which primarily deploy them[5]. The given categorisation into four types is rather rough as numerous different executions can be observed in the field. With respect to the basic structural form all four types belong to the group of pole-supported tents i.e. the fabric is tensioned over one or more supporting, individual poles and anchored to the ground by guy ropes. The ridge tent is the traditional relief tent which exists with very different heights of the side walls (see Figure 5.1). The centre pole tent with high walls is the former standard tent of the UNHCR which has been widely deployed not only after natural disasters but – due to the mandate of the UNHCR – especially for refugees. It is nowadays substituted by the Light Weight Emergency Tent (LWET), a hoop tent which has been tested by the UNHCR since 2002 and has already been acquired in large quantities for the UNHCR stocks (see Figure 5.2).

The LWET belongs to the so called second generation of relief tents which uses synthetic materials instead of traditional canvas. To understand the ongoing discussion

Pictogram (Structure in red)				
Type	**Ridge**	**Centre pole - high wall**	**Centre pole - low wall**	**Hoop**
Description	Traditional relief tent; standard relief tent of many agencies	UNHCR standard family tent		2^{nd} generation relief tent
Floor area	12 - 16 m^2	16 m^2	18 m^2	13 - 19 m^2
Centre height	2 - 3 m	3 m	2.4 m	2.0/2.1 m
Side wall height	0.9/1.0 m	1.8 m	0.6 m	–
Usual covering	canvas or poly-cotton	canvas or poly-cotton	canvas or poly-cotton	synthetic materials
Weight*	60 - 85 kg	115 kg	25 - 35 kg	40 kg
Supplying agencies	ICRC, IFRC, IOM, MSF, UNHCR, UNICEF, World Vision, UNDP/IAPSO	UNHCR, UNDP/IAPSO	MSF, various Red Crescent Societies	IFRC, IOM, Oxfam, UNHCR
CHARACTERISTICS:				
Good headroom	–	√	–	√
Lightweight	–	–	√ (single fly version)	√
Rot resistant	–	–	–	√
Proven design	√	√	√	–
Large production capacity	√	√	√	√

* Weight without winterisation; large variations in weight arise from different executions in single/double fly

Table 5.1: Types of family tents for humanitarian aid

Figure 5.1: Ridge family tent

Figure 5.2: Light Weight Emergency Tent of UNHCR

about the benefits and drawbacks of the second generation tents it is useful to have a closer look at the advantages and disadvantages of the new development:

Advantages

- Stockpiling over many years possible as synthetic material unlike canvas does not rot

- Lower shipping cost and easier handling due to smaller volume and weight (41.5 kg compared to 80 - 110 kg for traditional canvas tents)

- Tunnel shape maximises headroom and usable space[6]

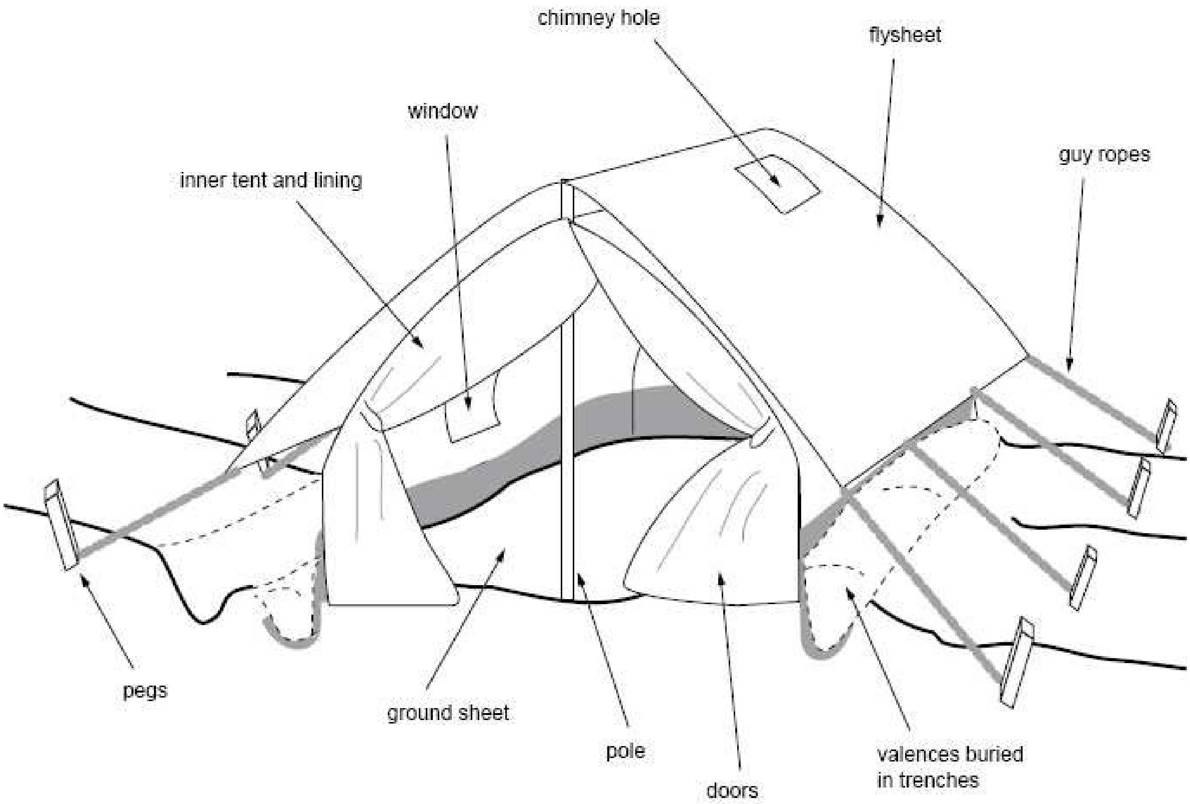


Figure 5.3: Components of traditional canvas ridge tent

Disadvantages

Arches of fibre-reinforced plastic are often of poor quality which makes them break

Under use less durable than UNHCR centre pole tent

Due to the observed problems the new design will certainly have to undergo modifications. Nevertheless, with regard to the leading role of the UNHCR within the shelter sector it seems useful to take the hoop tent as the basis for the below following development of a winterisation kit.

5.2.3 Components of Family Tents for Humanitarian Aid

Going a bit more into the details of the tents, Figure 5.3 illustrates the components of a traditional canvas ridge tent. Although the layout of other tent types varies significantly the denominated components are characteristic for all disaster relief tents.

Figure 5.4: Inner view of tunnel tent with quilt for insulation

5.3 Family Tents for Humanitarian Aid in Cold Climates

Despite the above highlighted need for tents as emergency shelters in cold climate disaster regions, adequate tents for this climate are not available. So far the necessary winterisation of tents is limited to double fly roofs plus potentially an insulating layer and openings for flue pipes as additions to standard family tents. The following three types of insulating layers exist:

a ***quilt*** made from felt filling (e.g. 100 g/m^2 polyester felt) stitched between two layers of the usual inner fly material which functions as an improved inner fly (see Figure 5.4)

a ***desouti liner*** (e.g. 170 g/m^2 cotton liner) which is added to the inner fly as an additional layer[7]

a 6 mm thick layer of ***bubble wrap*** with one aluminised surface which is placed in between the outer and the inner fly on top of the tent hoops (see Figure 5.5 and Figure 5.6)[8]

All three of them raise the thermal resistance of the roof and reduce the heat loss from draughts which can be significant due to the light construction of tents[9]. However, the carried out analysis of the thermal behaviour of all three roof options showed that none of them provides a sufficient insulation to prevent an excessive overall heat loss, to guarantee thermal comfort by appropriate surface temperatures and to avoid condensation on the inner tent surface. For a more detailed insight in the thermal processes and the actual behaviour of the roof it shall be referred to Chapter 8.3 (p. 139). Considering

Figure 5.5: Roof construction with aluminised bubble wrap insulation of Ovit, Tecimer winterised tent

the thermal performance of the roof it shall not be neglected that the delivered design due to its insufficient winterisation is often upgraded by local improvements. These improvements are made either by the delivery of additional non-food items (NFIs) (e.g. plastic sheeting acting as an additional roof layer or blankets blocking draughts) or by local solutions such as digging the tent into the ground to reduce the air infiltration through the walls. The second above listed winterisation feature, the flue hole, makes it possible to install a stove with a flue pipe within the tent. Together with other NFIs for cold climates such as blankets for sleeping it makes an essential contribution to raising the thermal comfort of the occupants which in the end can only be achieved by an interaction of the shelter and the NFIs.

With respect to the winterisation of the tent floor it has to be summarised that so far the packages of winterised tents do not provide other than a sewn in plastic groundsheet. An attempt to provide a basic floor insulation has been undertaken by the tent manufacturer HSNDS (H. Sheikh Noor-ud-Din Sons Private Limited) introducing a floor mat (100 % synthetic yarn, 500 g/m^2) which covered the entire tent floor as an optional enhancement of its light weight winterised family tent (LWWFT)[10]. However, due to the response of the aid agencies recent versions of the LWWFT (now LWWT for Light Weight Winterized Tent) do no longer offer this enhancement. Therefore, if attempts for the essentially needed floor insulation have been undertaken so far, these are either made by the delivery of additional NFIs i.e. plastic sheetings (against water infiltration), blankets, mattresses or floor mats (same material as suggested for LWWFT but smaller in size, i.e. 1.8 x 0.9 m) or by improvised solutions with whatever is locally available e.g. piled up clothes. Concluding, it has to be summarised that the little additions to 'normal' tents can not create an adequate shelter for cold regions. To get an overview and a deeper insight of what shelter aid in cold climates can actually be like, the subsequent chapter will present the case study of the Düzce-Bolu earthquake.

Figure 5.6: Roof construction with aluminised bubble wrap insulation of Ovit, Tecimer winterised tent

5.4 The Example of the Düzce-Bolu Earthquake: Family Tents deployed in Cold Climates

5.4.1 Introduction

The present OCHA (UN Office for the Coordination of Humanitarian Affairs) documentation of the Düzce-Bolu earthquake is one of the rare opportunities for getting a complete insight in the delivered emergency shelter aid as usually such documentation is not elaborated[11]. Therefore, this case study will be exploited to provide a complete cross section of the delivered tents in a cold climate disaster and to evaluate the appropriateness of the emergency shelter aid with respect to its winterisation and the achieved thermal comfort for the affected.

5.4.2 Disaster Background

On 12 November 1999 an earthquake of 7.2 Richter scale magnitude stroke the Düzce and Kaynasli counties in the north-western province of Bolu. It left 845 people dead, 55 000 homeless and damaged over 5 880 houses or business premises[12]. In the consequence, in spite of the very adverse climatic conditions, thousands had to be sheltered in tents often pitched up in tent cities with some thousand tents (see Figure 5.7). In view of temperatures well below 0 $°C$ Turkish authorities had raised an appeal for winterised tents which however could not be satisfied by the quality of the delivered tents. The situation was additionally worsened by strong winds, snow and heavy rainfalls which flooded tent cities[13].

Figure 5.7: Tent city after Düzce-Bolu earthquake

5.4.3 Winterisation of Tents

The present OCHA documentation shows that a large variety of tents has been dispatched in the disaster area. Beside the 8 tent types from Turkey 14 foreign countries delivered tents summing up to a total number of 34 different tents dispatched. Consequently very different executions with respect to the tent type, the floor area, the used material and the maximal number of occupants were observed.

Winterisation of Roof

Having a closer look at the winterisation features of the tents it was found that, in spite of the appeal for winterised tents and the very cold climate, the majority of tents (62 %) were not winterised (see Figure 5.8). Furthermore, 69 % of the tents defined as winterised did not have an insulation, which clearly leads to a very poor winterisation quality. With respect to all delivered tents this signifies that only 12 % of the tents had an additional insulative layer.

To get an understanding of what this means for the thermal conditions, the achievable internal tent temperature for a heated tent and an outside temperature of -10 $°C$ was calculated. For this purpose three different types of tent roofs were distinguished i.e. single fly, double fly and double fly plus insulation. This new distinction, differing from the one of winterised and non-winterised tents, is necessary as for the before mentioned distinction the number of layers and hence the thermal property was not unambiguous. (E.g. there are winterised tents featuring a heavy single layer while non-winterised tents are executed with a double fly.) This unsystematic categorisation has to be seen as symptomatic and as a clear

Figure 5.8: English summer tent without water resistant treatment

indication of the missing understanding of what a winterised tent should as a minimum feature. As basis for the calculations the UNHCR centre pole family tent was used as its tent type was most frequently deployed (i.e. 53 % of the tents were centre pole - high wall tents). The results are given in Table 5.2 either for a heater output of 5 kW and 6 occupants (i.e. Q=5 600 W as each person is assumed to produce 100 W of heat) or for the maximal heater output of 7 kW and 8 occupants (i.e. Q=7 800 W). It can be seen that for the single fly version for both heat inputs a comfortable temperature within the tent can not be obtained. The same applies to the double fly version for 5 600 W, whereas here for the higher heat input acceptable values are being achieved. Insulating the double fly version, a temperature increase of about 2 $°C$ is realised. In reality this value should even be higher as the additional layer signifies a better sealing of the tent and a thereby reduced heat loss from infiltration (see also Chapter 5.3). However, due to a lack of appropriate data the calculations do not account for this. All temperatures are given for an air change rate of 4 ac/h (**a**ir **c**hanges per **h**our), which fits for a double fly tent but is too pessimistic for the insulated version and too optimistic for the single fly tent[14]. Evaluating the obtained results it has additionally to be kept in mind that the given temperatures are air temperatures and that the thermal comfort is determined as a combination of air temperatures and surface

Roof layout	**Int. air temperature**	
	Q=5 600 W	Q=7 800 W
Single fly	6 $°C$	13 $°C$
Double fly	15 $°C$	24 $°C$
Double fly plus insulation	17 $°C$	27 $°C$

Table 5.2: Temperature within tent for different roof layouts and heat inputs

temperatures. Considering the low insulating capacity of the tent's roof and the consequently large proportion of temperature decrease towards the inner surface of the roof the thermal comfort will be adversely affected.

Fuel Consumption

Calculating in addition the fuel consumption for a continuous heater output of 5/7 kW it can be seen that the winterisation of tents is not only important with respect to thermal comfort but as well for the required supply of the affected with fuel and for ecological sustainability. For a 5 kW heat output a stove consumes within one week 310 kg air dried firewood (i.e. 0.8 m^3) or 106 kg kerosene (0.1 m^3) which, with hundreds of tents in need of heating, sums up to a large demand. For insufficient winterisation it can be assumed that the stoves will have to work continuously at their maximal capacity (i.e. 7 kW) which signifies an additional increase in the fuel consumption by 40 % to 434 kg wood and 148 kg kerosene per week. The consequences of this fuel demand are either high costs and logistical efforts for the delivery of fuel or the often displayed danger of deforestation as the affected have no other access to fuel than to collect firewood within their vicinity. For both cases the insulation of tents appears even more pressing.

Installation of Stoves

The calculations above showed that a stove is an essential component for tent winterisation. However, evaluating the Düzce-Bolu earthquake documentation it can not be determined how many of the tents delivered had a flue hole and therefore allowed for the installation of a stove.

Provision of Flooring

The fact that only 50 % of the tent types delivered provided some kind of flooring shows the prevailing neglectance of flooring as an essential winterisation feature for the creation of a comfortable inner tent climate and highlights the strong need for development.

Water Resistance

Having considered so far the protection against cold another important feature in the context of cold climate disasters is the water resistance of the shelter as the affected regions usually have large precipitations, be it as snow or rain. In spite of monthly precipitations of more than 4 cm in the Düzce region, 26 % of the delivered tent types were not water-resistant and, as already mentioned above, 50 % did not provide flooring[15]. Although the delivery of additional flooring material is possible, this can not abolish the problem of water seeping into the tent through the gap between flooring and tent walls which occurs if the floor is not sewn in during manufacture. In view of frequently occuring flooding of entire tent cities this is a serious problem which not only causes discomfort for the occupants but as well destroys their little remaining belongings as they can not be stored elsewhere than on the floor.

5.4.4 Conclusion

It has to be concluded that in spite of an appeal for winterised tents the delivered tents are by far inappropriate for the local climate and that the design of more appropriate shelters which are subsequently available for future disasters is strongly necessary.

5.5 Non-Food Items for Humanitarian Aid

Although the subject of this chapter are tents, the large contribution of non-food items (NFI) for humanitarian aid like bedding to providing a proper shelter against adverse climates justifies that they are dealt with in this context. Giving the specifications and the way of application of the relevant NFIs it becomes apparent how they contribute to the shelter, and the entire living situation of the homeless can be perceived.

As the thermal comfort of the homeless during sleeping is of great importance, first of all the NFIs for bedding shall be discussed. They consist of blankets, quilts, sleeping bags and mattresses. Of these, blankets are of major interest, as the other items are usually delivered only in minor quantities. For example within 120 days after the Pakistan earthquake the UNHCR as Camp Management Cluster Lead had delivered 500 000 blankets, 6 000 mattresses, 3 500 sleeping bags and no quilts[16]. Although in cold climate regions the good insulating qualities are strong points in favour of mattresses, sleeping bags and quilts, the quantities demonstrate the predominant restriction to blankets as bedding material. This derives from the cost and volume of the other NFIs. Due to the relevance in the field, in the following only a detailed description of blankets will be given, supplemented by one of mattresses which are further below of importance due to their quality as floor insulation.

5.5.1 Blankets

Blankets have a size of 1.5 x 2.0 m and are made either from a mix of wool and cotton or from polyester. They are available in three qualities (low, medium and high thermal (th.) resistance blankets) which are obtained by different material thicknesses (see Table 5.3 which gives the thickness under 20 g/cm^2 load) and for those made from cotton/wool by increasing the wool proportion for higher thermal resistances[17]. To give an idea of the costs of the NFIs the indicative prices[18] from the ICRC Emergency Items Catalogue 2004 will be given in this section[19]. Together with the average thermal resistance of the uncompressed blankets (R_{up}) it is given in Table 5.3 for the medium and high

blanket type	$d_{20\ g/cm^2}$	R_{up}	indicative price
low th. resistance	4 mm	–	–
medium th. resistance	4 - 6 mm	0.20 m^2K/W	4.50 CHF
high th. resistance	6 - 8 mm	0.30 m^2K/W	8.00 CHF

Table 5.3: Blanket specification

thermal resistance blankets as only these two are subsequently of interest due to their good insulating capacity. Given their comparably large availability and their universally deployable, good thermal insulation, blankets not only serve as bedding but as well as sitting mats during the day, for improving the doors or roofs of the tents or even as garments.

5.5.2 Mattresses

Mattresses from polyurethane closed cell foam can be found in sizes of 0.8 x 2.0 m or 0.9 x 1.9 m and generally have a thickness of 10 cm [20]. The cost indicated by the ICRC is 25.00 CHF per piece. Lain immediately on the tent floor they are used for sleeping or sitting. Although the good insulating property of the mattresses towards the cold ground underneath the tent is known, their application has been very restricted because of a generally observed reluctance to transport the bulky material into the disaster area.

Beside the bedding the subsequently discussed NFIs i.e. floor mats, plastic sheeting and stoves contribute to providing a comfortable and warm shelter.

5.5.3 Floor Mats

Floor mats or sleeping mats, as they are called as well, are available in various sizes e.g. 0.9 x 1.8 m. They are made from natural or plastic straw, plastic strips or woven synthetic yarns[21]. The cost indicated by the ICRC is 2.20 CHF per piece. They are used to cover the ground sheet or plastic sheeting of the tent floor in order to make the tent more habitable and provide some insulation to the ground. Even though not deployed in the large quantities of blankets, they are supplied rather frequently.

5.5.4 Plastic Sheeting

Plastic sheeting or tarpaulin, as it is frequently named, is delivered with a width of 4 m either as single pieces of 5/6 m length or as entire rolls with 50/60 m length. It is usually manufactured of high density polyethylene (HDPE) which is coated on both sides with low density polyethylene (LDPE) and in some cases a reinforcement with bands of HDPE fibers fabric exists. To allow a fixing of the plastic sheeting it usually

Figure 5.9: Wood/coal stove

features eyelets every 1 m along its borders[22]. The indicative price of the ICRC for a single sheet (4 x 6 m) is 15 CHF, the one for a roll (length 60 m) is 180 CHF. Due to its very universal applicability plastic sheeting is widely used for shelter aid be it as an emergency shelter constructed with plastic sheeting and some supporting poles, as an improvement for tents or as a temporary roof on a partially destroyed house.

5.5.5 Stoves

There is a wide choice of different stoves available which stems among others from local habits and availability. In general very basic stoves, serving for cooking and heating, are supplied (see Figure 5.9). Due to their set-up within the tent they require a flue pipe. Usually wood or kerosene are used as fuels and a heat output of 5-7 kW is generated[23]. As other shelter needs like the protection from rain and snow or the personal insulation (e.g. by clothing) are more pressing, heaters are often delivered with a certain delay after the disaster and not all tents get equipped with one, even though in cold climates they are essential for reaching a comfortable internal air temperature.

5.6 All-Season Camping and Polar Tents

Due to the usage in similar climates it seems helpful to have a close look at all-season camping and polar tents to find out whether a transfer of concepts is feasible (see Figure 5.10). For this purpose the key features of winterised tents shall be regarded i.e. insulation, structural stability and ventilation. However, it has to be kept in mind

Figure 5.10: Hilleberg's hoop tent Keron for winter camping and polar expeditions

that a possible transfer always needs to consider the general difference between the two types of tents. This is first of all a large difference in cost with camping tents being much more expensive[24]. Subsequently, the observed difference in cost influences the choice of material with expensive high-tech materials being only used for camping tents. Secondly, different requirements of space per person lead to a difference in proportion and consequently in the required structure to cover the area. To house 4 persons a camping tent with a floor area of 4.4 m^2 (i.e. 1.1 m^2 per person) might be used, whereas for 5 persons the ICRC standard family tent offers 16 m^2 (i.e. 3.2 m^2 per person)[25]. This difference is owed to the different functions of the tents: The first type purely serves as a place to sleep protected from the climate while the second one widens its function towards a place to live in (see Chapter 4.3).

5.6.1 Insulation

As the shell of all-season camping and polar tents consists of two thin layers without any additional insulation, it only functions as wind break and to reduce conduction[26]. The necessary insulation of the occupants is provided by maximising the personal insulation i.e. by clothing and bedding. Considering the high performance clothing of participants of polar expeditions with a thermal resistance of 3.5 Clo (i.e. unit for measuring clothing's insulation with 1 $Clo = 0.155\ m^2K/W$ and R = 1 Clo for a normally dressed person), the minimal required temperature for thermal comfort after DIN EN ISO 7730 was calculated to be 0.5 $°C$ [27]. Analysing the situation during sleeping for the standard winter camping bedding of a winter sleeping bag and either a 12 mm mat of closed cell foam or a 30 mm self-inflating sleeping mat, it could be found out that for a temperature of -20 $°C$ in the tent and of -10 $°C$ for the ground the occupants are comfortable even

Figure 5.11: The North Face VE-24 geodesic dome: successor of the first geodesic dome camping tent, the Oval Intention

without wearing any clothes[28]. This means that, in spite of a very poor insulation of the tent and a very low internal tent temperature, thermal comfort is obtained. In contrast, the insulation by clothing and bedding of homeless and refugees is much poorer, as no such high quality bedding and clothing will be available. Taking from past disaster situations the maximal achievable personal insulation by clothing of 1.82 Clo, a minimal temperature of 15.6 °C is required within the tent for thermal comfort. Consequently an insulation of the tent is necessary and the concept of a restriction to personal insulation can not be overtaken from the field of camping and polar expedition equipment[29]. Additionally, it has to be considered that family tents can not be limited to providing survival conditions but are attributed as well a quality as living space, which could not be satisfied with very low internal temperatures.

5.6.2 Structural Stability

With the application of Buckminster Fuller's theory of intersecting triangles to the design of camping tents in the late 70's and the evolution of geodesic domes a revolutionary, very stable structure was found, that is still used for many tents (see Figure 5.11). It proofed to be capable of taking strong wind and snow loads. As a free-standing tent type no guy ropes are required to raise the tent, which is an indicator for the stability and eliminates the problem of weaknesses due to wrongly executed guy ropes which is a frequently observed problem for family tents[30]. The second major all-season camping tent type is the hoop tent which is very popular in Europe and employed for the new Light Weight Emergency Tent (LWET) of the UNHCR (see Figure 5.10)[31]. It requires guy ropes for assembly and can take less snow load than geodesic domes. Considering the very adverse weather conditions in some disaster regions, the long period of use and the additional

Figure 5.12: Vents in Hilleberg tents

problem of weaknesses introduced by improper guy rope positioning it seems more useful to chose a geodesic dome instead of the nowadays applied hoop tents. Although this means in the first place an increase in transport weight as geodesic structures are heavier than those for hoop tents, this will pay out in the end as no additional tents for the replacement of destroyed ones will have to be delivered[32]. Profiting from the experience in the camping and polar expedition field, Chapter 8.4.2 will therefore highlight the use of a geodesic design as a fruitful starting point for further research towards a winterised tent with increased structural stability.

5.6.3 Ventilation

In cold climates ventilation is needed to remove warm, moist air from the tent and to keep condensation as low as possible. For this purpose camping and polar tents feature an inner tent, that is permeable to air, allowing the moisture to flow out of the inner tent and vents, that are placed high up in the outer tent, venting warm, moist air by means of the chimney effect out (see Figure 5.12)[33]. As problems with condensation have frequently been observed for family tents in cold climates and vents have in most cases not or only very rudimentarily been deployed so far, Chapter 8.3.1 will explain in detail how a transfer of this concept can be exploited for an improved winterised family tent.

5.7 Nomad Tents

Another type of tent used to house people in cold climates is the nomad tent (see Figure 5.13). In contrast to the before discussed camping and polar tents which reduced the functions of shelter to providing purely survival conditions, the functions of nomad tents can be seen as an extension over the shelter functions associated with family tents: The intention is no longer to provide an adequate shelter for a limited period of time, but to serve as permanent housing even though under the constraint of full mobility. Nomad tents proof that with the continuous improvements over generations a perfect

Figure 5.13: Set-up of Mongolian yurt with wooden lattice and felt covering

shelter can be achieved even under the very difficult boundary conditions of mobility and cold climates which they have in common with family tents. The result of these improvements are structures that perfectly correspond to the living conditions using the available raw materials and the accordingly developed techniques for their treatment as well as the available means of transport: The large livestock of nomads provides the raw material for well insulating materials such as felt and pelt and allows for the transport of tents with a weight of some hundred kilos[34]. As the living conditions of the affected of natural disasters are generally very different, they do not have access to such raw materials nor have the skills and time for their treatment. At the same time an external procurement is impossible due to its high costs. Furthermore, with no means of transport other than their own man power, the weight of the tents needs to be restricted to bellow hundred kilos, which excludes the use of the very stable wooden structures of nomad tents as shown in Figure 5.13. This additionally impedes the use of the very heavy multi-layer insulation concept, which referring to the lack of material therefore can be seen as twice unfeasible. It has to be concluded that, in spite of the excellent performance of nomad tents, a transfer of technology neither for the insulation nor for the structural stability of winterised family tents is possible.

Notes

[1]The Sphere Project (2004)
[2]The Sphere Project (2004), p. 219
[3]The Shelter Centre is a NGO supporting communities impacted by conflicts and natural disasters by serving collaboration and consensus in humanitarian transitional settlement and reconstruction response.
[4]For updates on the progress see URL: http://www.sheltercentre.org → Shelter Module.
[5]Adaption from Corselli (2004), p. 288; further sources: Ashmore (2002), pp. 13-15, p. 26; HSNDS (2007)
[6]International Aid + Trade (2007), p. 121
[7]HSNDS (2007a)
[8]Tecimer (2007)
[9]Shelterproject.org (2005)
[10]As the recent versions do no longer offer the enhancement, there is not anymore information available on the homepage of HSNDS. Original source: HSNDS (2006)
[11]OCHA, local Red Cross Society (1999)
[12]EM-DAT (2007)
[13]IFRC (1999); Agence France-Presse (AFP), Ankara (1999)
[14]Manfield (2000), p. 20
[15]MSN Weather (2007)
[16]UNHCR (2006a)
[17]Ashmore (2002), p. 28
[18]Indicative price: 'Bid or offer price provided by way of information rather than as the level at which a trader is willing to trade. Indicative prices enable a customer to plan a transaction but the transaction does not proceed until firm prices are provided.' (Australia and New Zealand Banking Group Limited (2007))
[19]ICRC (2004), Volume 1 - Housing - Shelter
[20]UNDP (2000), p. 58; ICRC (2004), Volume 1 - Mattress
[21]ICRC (2004), Volume 1 - Mats, for floor
[22]UNDP (2000), pp. 35-38
[23]UNHCR (2006b), p. 146
[24]For example: Price for a 4.4 m^2 high quality all-season camping hoop tent: 869 € (Hilleberg (2007), Keron 4); Price for a winterised family tent of about 16 m^2: ~200 $.
[25]Hilleberg (2005), p. 20; ICRC (2004), Volume 1 - Family Tent
[26]Hilleberg (2005)
[27]Manfield (2000a), p. 11; DIN EN ISO 7730 (2006-05)
[28]Hilleberg (2007a); For detailed information on the applied calculation method to determine the comfort during sleeping see Chapter 8.2.
[29]Manfield (2000a), p. 12
[30]OCHA (2004), p. 20
[31]Hitz (2007)
[32]Hilleberg (2005), p. 17
[33]Hilleberg (2005), p. 13; Hilleberg (2007b)
[34]Ashmore (2003), pp. 278/285; Manfield (2000a), pp. 3-4, p. 6

Chapter 6

Floor Insulation for Emergency Shelters - Fundamentals

6.1 Introduction

The examples given above have clearly indicated the need for improved winterisation of family tents. Within this task the provision of appropriate flooring is of high importance as it is not only essential for obtaining a comfortable air temperature within the tent but additionally minimises conductive heat loss from occupants sitting or laying on the floor. Especially during sleeping this is crucial as excessive heat loss can result in illnesses or even death[1]. In reaction to the demand expressed by various organisations providing emergency shelter the subsequent two chapters will investigate the possibilities of the provision of insulated tents floors. The first chapter will deal with the fundamentals such as requirements for the floor which then form the basis for the actual development of different floor options in Chapter 7.

6.2 Requirements

6.2.1 Life Cycle of Insulated Floor

Before moving on to the actual development of an insulated tent floor it is essential to define the requirements which the floor has to fulfil. This was done by evaluating experiences from past disasters as given in the literature as well as by consideration of personal comments made by experts working in the field of emergency shelter aid in NGOs, UN agencies as well as by tent manufacturers.

The definition of the requirements can be done best regarding the life cycle of the insulated tent floor as depicted in Figure 6.1. From availability to dismantling all important steps are indicated. It has to be noted that the requirements do not only arise

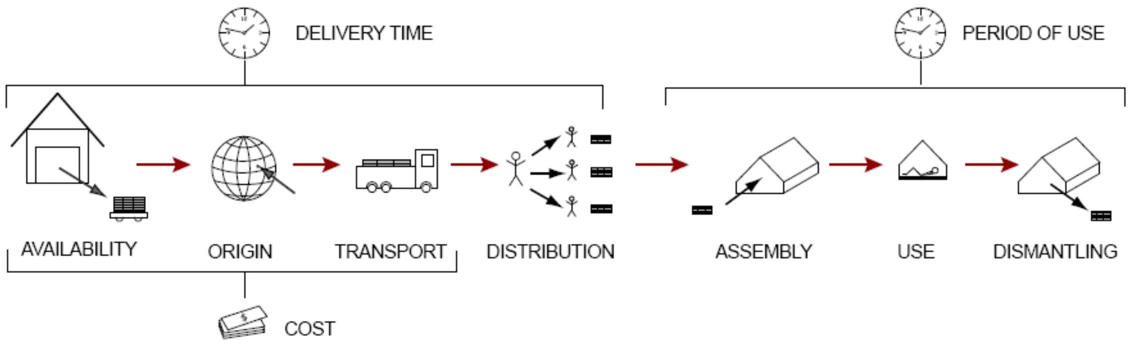


Figure 6.1: Life cycle of insulated tent floor

from the function which the floor has to satisfy during its use, but as well from the overall context in which it is employed. In Figure 6.1 the context is represented by all requirement criteria beside the use. Due to its very specific characteristics the fulfilment of the depicted requirements becomes rather difficult even though at the first glance it seems very easy considering only the requirements from the function like insulating a component.

6.2.2 Requirements from Context

Distinguishing between the two groups of requirements first of all it will be dealt with those from the context by identifying the boundary conditions of the given context and deriving from these the actual requirements. For those requirement criteria, where different options of boundary conditions exist, a diagrammatic depiction has been applied in order to allow for a visualisation of the different sets of requirements provoked.

Delivery Time / Availability

These two criteria are interrelated, as for a disaster striking in winter an immediate delivery is necessary and therefore an immediate availability of the materials. On the contrary, given a long preparation period in case of a disaster happening in summer, a long delivery time of the material is feasible. Figure 6.2 illustrates how from the boundary conditions of the delivery the corresponding requirements are derived (red box) which simultaneously form the boundary conditions of the availability resulting in the final set of three different requirements (blue box).

Origin / Transport

In the same way the origin of the delivered materials defines the boundary conditions of the transport resulting again in three sets of requirements as depicted in Figure 6.3.

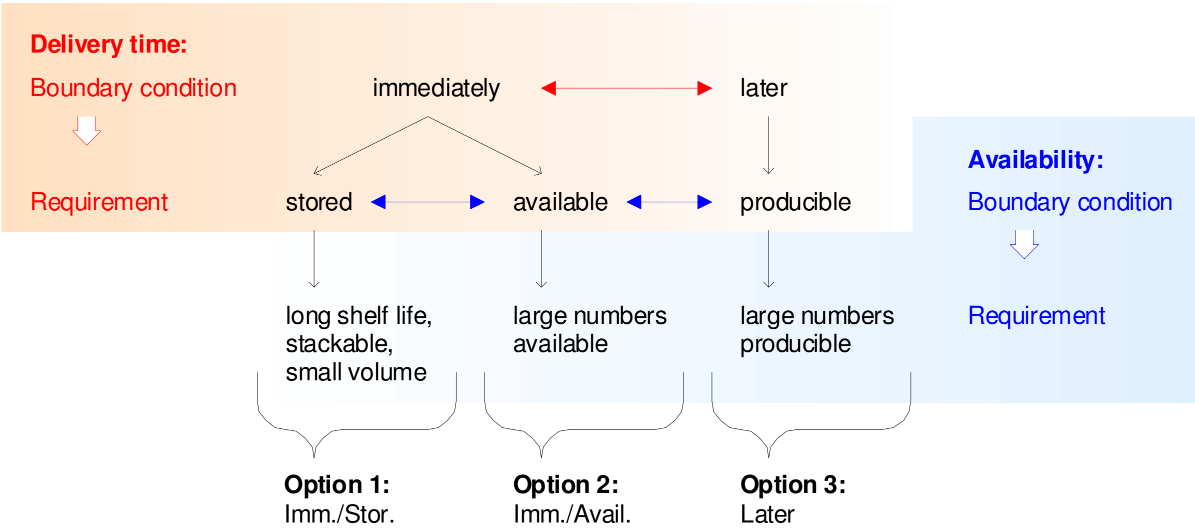


Figure 6.2: Requirements from delivery time / availability

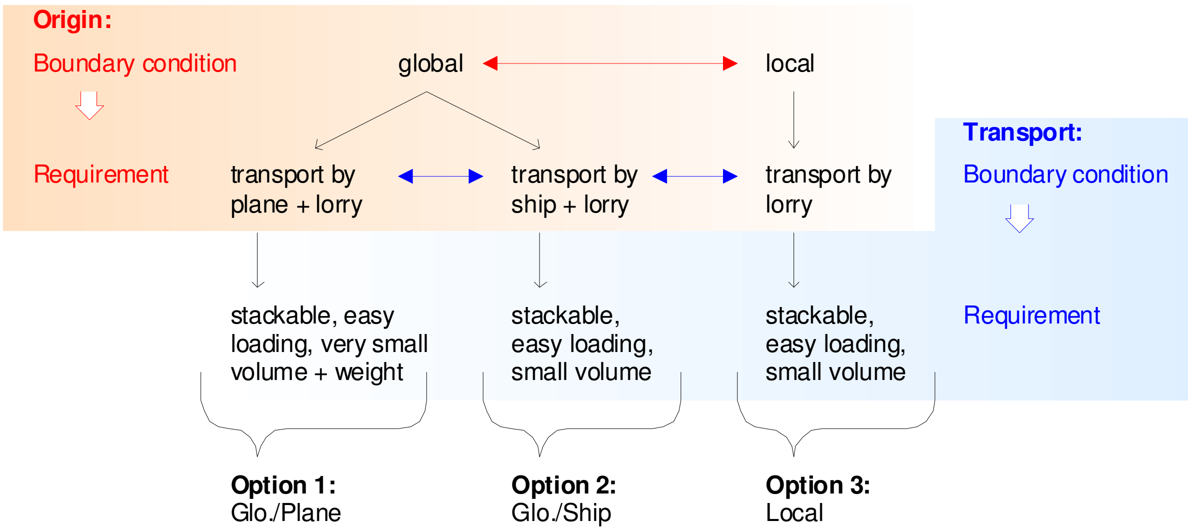


Figure 6.3: Requirements from origin and transport

Cost

As the bracket in the live cycle diagram already indicated, the cost of the floor depends on various other criteria that form the boundary conditions for the overall cost. Figure 6.4 shows how the before discussed options for delivery time/availability and origin/transport influence the composition of the overall cost for the floor.

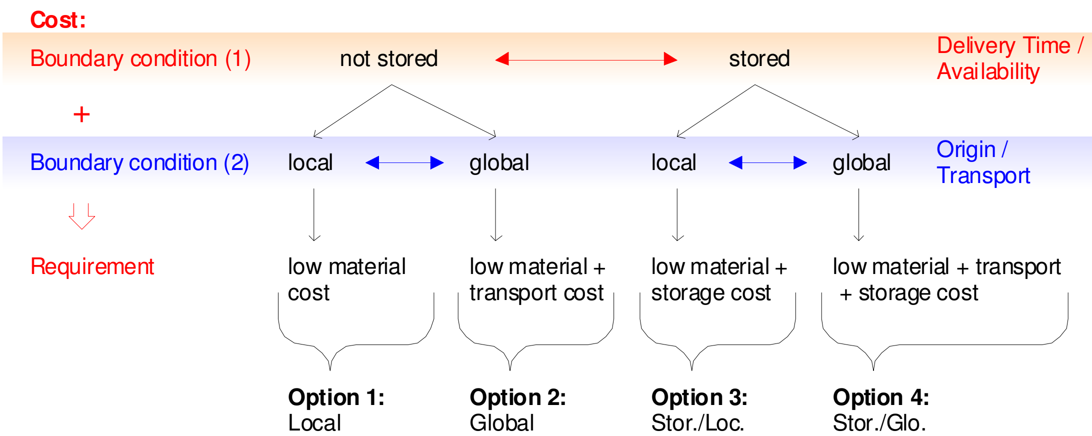


Figure 6.4: Requirements from cost

Distribution

For the distribution two different scenarios are feasible depending largely on the applied emergency shelter policy with people either staying in camps (i.e. central delivery) or self-settling (i.e. individual collection) (Figure 6.5). Another, invariable boundary condition is the ***ease of distribution***. This generates the requirement of fitting all components in ***one single package*** in order to avoid that only unusable parts of the entire floor are available.

Assembly

The assembly has to be possible ***without external help*** which generates the requirement of being ***self-explanatory*** and a ***misuse being impossible***. The second boundary condition for the assembly is that the insulated floor has to ***cover the entire tent ground*** which leads to a requirement of ***material for 15 - 20 m***^{2}. Finally, due to different sheltering situations of the affected it should be accounted for ***a flexibility in use*** of the delivered items from which raises the requirement to ***distribute indeterminate materials***.

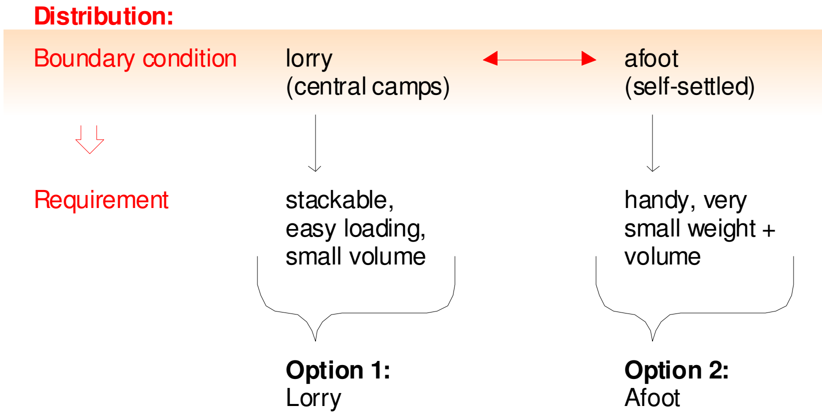


Figure 6.5: Requirements from distribution

Period of Use

As the boundary condition for the deployment of the floor is to ***serve for one winter***, ***functionality for 6 months*** is required.

Dismantling

As for every other relief item it is important to consider ***sustainability*** which leads to the requirement of ***ecological sound disposal or reusability*** for transitional shelters or reconstruction. Additionally, it has to be made sure that whatever function the product might get ***after its intended use*** it can ***not do any harm***[2].

6.2.3 Requirements from Function

The requirements from the function of the floor can be derived from the given impact either on the top or the bottom surface of the floor as shown in Table 6.1.

6.3 Calculation Method for Heat Transfer through Floor

As the insulating property of different floor options is of large importance its calculation and evaluation will be made possible by first of all giving a general overview about heat transfer processes. Subsequently, the relevant building codes and their applicability or adaptability will be investigated in order to gain a calculation method for the heat loss through the floor. Moreover, this approach is sensible in view of the fact that many floor

Surface	Impact	Requirement
TOP	water	water-repellent
	fire	flame-resistant
	heat (from stove)	heat-resistant
	wear and tear	resistant to wear and tear
	local loading	rigid
	piercing or cutting objects	no loss of insulating air
BOTTOM	water	not permeable for water, rot-proof
	cold	insulating
	frost	frost-resistant
	rough ground	slightly flexible
	vermins	indestructible by vermins
	piercing or cutting objects	no loss of insulating air

Table 6.1: Requirements from function

designs will integrate building materials which are standardized according to building codes. In conclusion a method for the calculation of thermal comfort will be presented.

6.3.1 Heat Transfer Processes

To give a general understanding of how heat is lost from the heated tent to its cold surrounding the heat transfer processes shall be investigated. The following three modes of heat transfer and the corresponding equations for the heat flux can be distinguished[3]:

1. ***Conduction:*** heat transfer through a matter from its hot to its cold part.
   After Fourier's law the heat flux q in W/m^2 is given by:

$$q = U \cdot (\theta_i - \theta_e) \tag{6.1}$$

with

$$U = \frac{1}{R} = \frac{\lambda}{d} \tag{6.2}$$

U	thermal conductance (in W/m^2K)
R	thermal resistance (in m^2K/W)
λ	thermal conductivity (in W/mK)
d	thickness (in m)
θ_i/θ_e	internal and external temperature (in $°C$)

2. ***Convection:*** heat transfer within a fluid by diffusion and advection.
   The heat flux is given by:

$$q = w \cdot c_p \cdot (\theta_1 - \theta_2) \tag{6.3}$$

w	velocity of flow (in m/s)
c_p	heat capacity (in J/kgK)
θ_1/θ_2	temperature (in $°C$)

3. ***Radiation:*** electromagnetic waves, which are emitted from an object due to its temperature.
   After the Stefan-Boltzmann law the heat flux is given by:

$$q = \epsilon \cdot \sigma \cdot T^4 \tag{6.4}$$

ϵ	emissivity (in –)
σ	Stefan-Boltzmann constant ($\sigma = 5.6698 \cdot 10^{-8}\ W/(m^2 \cdot K^4)$)
T	temperature (in K)

In order to reduce the heat flux out of the tent two options have to be considered: a reduction of the conductive heat loss by increasing the thermal resistance R of the deployed insulating layers or a reduction of the radiative heat loss by decreasing the emissivity ϵ of components with air contact.

6.3.2 Applicability and Adaption of Building Codes

As for the insulation of tents no requirements or codes exist the resemblance to buildings shall be exploited to develop from building codes a procedure to calculate the insulating capacity of different tent designs.

DIN EN 12831

In DIN EN 12831 the required heater capacity is determined by calculating the heat loss by transmission[4]. This is as well of interest for the evaluation and comparison of different tent designs Therefore, based on the methods used in DIN EN 12831 and the above given general equations for heat transfer, the heat loss Q via a component can be determined as:

$$Q = q \cdot A = U \cdot A \cdot (\theta_i - \theta_e) = \frac{1}{R_T} \cdot A \cdot (\theta_i - \theta_e) \tag{6.5}$$

A size of component (in m^2)
R_T total thermal resistant of component (in m^2K/W)

DIN EN ISO 6946

To simplify the calculation of the heat loss by convection and radiation their contribution shall be calculated as in DIN EN ISO 6946 [5]. The code accounts for convection and radiation by uniting them in a resistance to heat transition either on the inner (R_{si}) or on outer (R_{se}) surface of a component. Consequently, the above given R_T becomes:

$$R_T = R_{si} + R + R_{se}$$

with

$$R = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + ...$$

R sum of thermal resistances of the component's layers (in m^2K/W)

DIN EN ISO 13770

The equation for R_T considers via R_{si} and R_{se} the standard case that both surfaces of the component are in touch with air. For the floor insulation, however, one side is in contact with earth that functions as an additional insulating layer. DIN EN ISO 13770 applies for this by introducing the thermal conductivity U_0 for components adjacent to earth[6]. Consequently U_0 is lower than the thermal conductivity of components with exclusive air contact. In order to check the applicability of DIN EN ISO 13770 for the given context, U_0 was calculated for the new generation UNHCR tent (covered area: 3 m x 5.5 m) and a floor insulation of 2 cm EPS (expanded polystyrene; $\lambda = 0.035\ W/mK$). For the thermal conductivity of the earth underneath the tent a conservative value i.e. a high thermal conductivity ($\lambda = 2.1\ W/mK$) was taken in order to get a result that fits for every ground condition. The obtained value $U_0 = 0.842\ W/m^2K$ is much lower than the one without consideration of the earth, i.e. $U = 1.280\ W/m^2K$. This means that an earth layer of 0.853 m thickness acts as insulation and that for $\theta_i = 20\ °C$ and $\theta_e = -10\ °C$ the contact temperature between the floor insulation and the earth raises to $\theta_{E1} = 0.27\ °C$.

This temperature signifies that starting from the initial unheated state, the temperature within the floor and the earth is increasing over time while heating. For a usual building it can be assumed that after a certain time of heating up, the temperature distribution implied in the code's model will be achieved and remain constant. In contrast to this, a continuous heating of the tent will not be feasible. Hence the warming up of the earth underneath the tent will be relatively restricted. In order to evaluate the feasibility of a warming up under the tent within a certain duration of heating a numerical difference method based on the Fourier's equation was deployed using the following equation:

$$\frac{\Delta\theta}{\Delta t} = a \cdot \frac{\Delta^2\theta}{(\Delta x)^2}$$

Δt	time step (in s)
a	thermal diffusivity (in m^2/s)
Δx	thickness of one layer (in m)

It allows the solution of Fourier's differential equation for unsteady temperature distributions and a one dimensional heat flux[7]. This means that only the heat flux perpendicular to the floor could be considered and not the one parallel to the floor. This restriction arises from the complex nature of Fourier's differential equation. However, due to the small area covered by the tent and the consequently large influence of the horizontal heat flux for the thermal situation under the tent, the obtained temperature distribution applies only for a small, central region under the tent. For the above given floor design and temperature difference the heating up of the earth was computed. After 24 hours (1 440 min) of continuous heating a temperature of $\theta_{E1} = Ts = -3.98\ °C$ was obtained for the contact of floor and earth (see Figure 6.6, Ts i.e. surface temperature of earth) which is, in spite of the long period of heating, considerably lower than the temperature obtained after the code ($\theta_{E1} = 0.27\ °C$). Taking additionally into consideration that due to the three-dimensional heat flux the contact temperatures along the border regions of the floor will be considerably lower it has to be concluded that the values for U_0 obtained after DIN EN ISO 13770 are too optimistic. Therefore, the insulating capacity of the earth under the tent will subsequently be neglected.

DIN 4108-2

Another question with respect to building codes is whether or not they can inform minimum requirements for the insulation. For components in contact with earth DIN 4108-2 gives as a minimal requirement for the total thermal resistance

9									
10	depth (m)				0,010	0,030	0,050	0,070	0,090
11	time (min)	Ti	T,0	Ts	T,1	T,2	T,3	T,4	T,5
909	1425,397	20,000	-3,864	-4,011	-4,157	-4,441	-4,717	-4,984	-5,243
910	1426,984	20,000	-3,862	-4,008	-4,154	-4,438	-4,714	-4,981	-5,240
911	1428,571	20,000	-3,859	-4,005	-4,151	-4,436	-4,711	-4,979	-5,237
912	1430,159	20,000	-3,856	-4,002	-4,149	-4,433	-4,709	-4,976	-5,234
913	1431,746	20,000	-3,853	-4,000	-4,146	-4,430	-4,706	-4,973	-5,231
914	1433,333	20,000	-3,850	-3,997	-4,143	-4,427	-4,703	-4,970	-5,229
915	1434,921	20,000	-3,848	-3,994	-4,140	-4,424	-4,700	-4,967	-5,226
916	1436,508	20,000	-3,845	-3,991	-4,137	-4,422	-4,697	-4,964	-5,223
917	1438,095	20,000	-3,842	-3,988	-4,135	-4,419	-4,694	-4,961	-5,220
918	1439,683	20,000	-3,839	-3,986	-4,132	-4,416	-4,691	-4,959	-5,217
919	1441,270	20,000	-3,837	-3,983	-4,129	-4,413	-4,689	-4,956	-5,214
920	1442,857	20,000	-3,834	-3,980	-4,126	-4,410	-4,686	-4,953	-5,211
921	1444,444	20,000	-3,831	-3,977	-4,123	-4,407	-4,683	-4,950	-5,209
922	1446,032	20,000	-3,828	-3,975	-4,121	-4,405	-4,680	-4,947	-5,206
923	1447,619	20,000	-3,826	-3,972	-4,118	-4,402	-4,677	-4,944	-5,203
924	1449,206	20,000	-3,823	-3,969	-4,115	-4,399	-4,675	-4,942	-5,200
925	1450,794	20,000	-3,820	-3,966	-4,112	-4,396	-4,672	-4,939	-5,197

Figure 6.6: Temperature change over time in earth underneath tent

$R_T \geq 0.9\ m^2K/W$ [8]. Attention shall be drawn to the boundary conditions of this requirement: firstly, the investment in insulation has to pay off within decades and not within months or maximal a couple of years as for the given context. Secondly, transport capacities are no problem as opposed to the case of natural disasters where access is very restricted and transportation costs can make up 50 % of the overall costs. Hence, the volume and weight of the insulation has to be minimised.

Given these two major differences it seems useful to derive separately a requirement for the tent floor. For this purpose the effectiveness of the insulation was evaluated by plotting the thermal resistance and conductivity over the thickness of an insulating layer as shown in Figure 6.7. Considering the above described floor design it can be seen how for an increasing thickness of the EPS layer its thermal resistance (R_{EPS}) increases while the total thermal conductivity (U_{total}) which is calculated for the complete floor design including two layers of tarpaulin reduces. Starting from zero and increasing the thickness of the EPS the initially large reduction in the thermal conductivity becomes smaller and smaller. Given the proportionality of U and the overall heat loss Q (see Equation 6.5) this signifies that the benefits obtained from an increase in insulation decrease with thicker EPS layers. As the aim of the floor insulation is not to keep the heat loss as low as possible but to provide with minimal investment in material an adequate living environment, a restriction to an insulating layer of less than 3 cm EPS is reasonable. Expressed in more general terms of the required total thermal resistance of

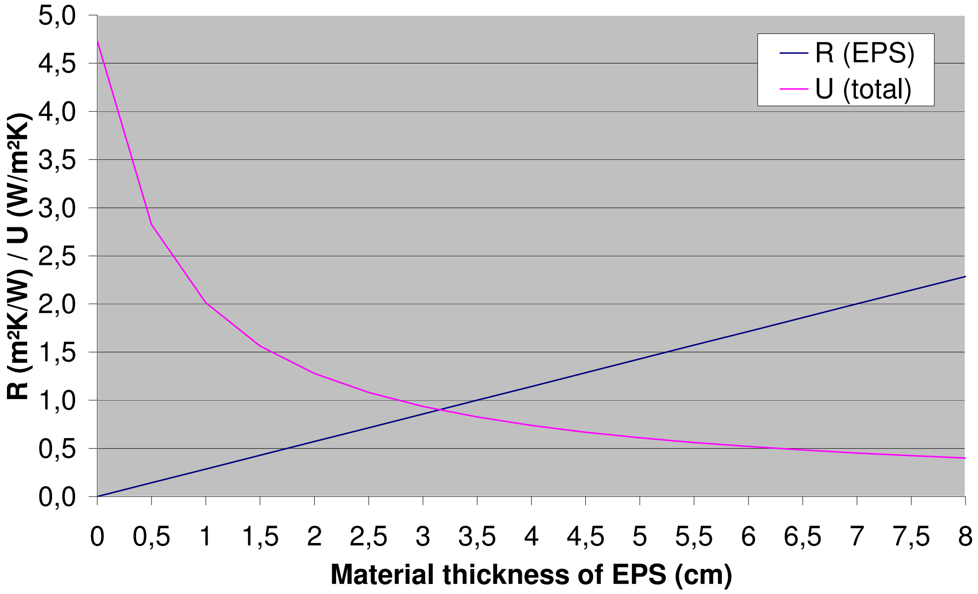


Figure 6.7: Thermal conductivity and resistance depending on thickness of insulating layer

the floor the following guidance can be gained from Figure 6.7:

$$0.8\ m^2K/W \leq R_T \leq 1.1\ m^2K/W$$

The minimal value corresponds to about 2 cm of EPS . This interval fits closely with the above given value after DIN 4108-2 and shall be used hereafter for the development of different floor designs.

6.3.3 Thermal Comfort after DIN EN ISO 7730

To evaluate different floor options not only their thermal properties as described above are of interest but as well the improvement in thermal comfort for the tent inhabitants. DIN EN ISO 7730 allows for the calculation of the percentage of people dissatisfied (PPD) considering the entire thermal situation within a room as well as the clothing and the activity of the inhabitants[9]. Of major interest is the determination of the percentage of dissatisfied (PD) depending on the floor temperature (t_f) which is calculated after:

$$PD = 100 - 94 \cdot exp(-1.387 + 0.118 \cdot t_f - 0.0025 \cdot t_f^2) \tag{6.6}$$

Given this equation the dependence of thermal comfort on the temperature of the surrounding surfaces is apparent so that a design not only for an appropriate air- but as well surface temperature (T_s) becomes necessary.

Notes

[1]OCHA (2004), p. 24

[2]E.g. after the South-Asia earthquake large amounts of corrugated galvanised iron sheets had been delivered for transitional shelters and later on used as permanent roofing with an insulating layer of 20 - 30 cm earth on top of it. Due to the poor quality of the corrugated galvanised iron sheets soon corrosion occurred threatening the collapse of roofs which can be seen as a significant risk introduced by the given disaster aid.

[3]Hohmann (2004)

[4]DIN EN 12831 (2003-08)

[5]DIN EN ISO 6946 (1996-11)

[6]DIN EN ISO 13770 (2005-06)

[7]Lutz (2002), pp. 144-147

[8]DIN 4108-2 (2003-07)

[9]DIN EN ISO 7730 (2006-05)

Chapter 7

Floor Insulation for Emergency Shelters - Design Options

7.1 Introduction

Having defined the fundamentals on which every floor design shall be based and evaluated, the subsequent chapter will deal with the actual design of various floor options. The developed options will be presented split up in three categories: building materials, miscellaneous materials and thin layer solutions. After the detailed discussion of each option the results will be summarised by firstly evaluating the thermal benefits of the solutions developed. Secondly, an easy to apply tool will be introduced allowing the selection of an appropriate floor insulation depending on the local climate. Concluding, a tabular summary of the fulfilment of the previously defined requirements for a floor insulation will be presented.

Given the task of developing an insulating component one preliminary thought is of large importance: as air is one of the best insulators, every design needs to include a significant proportion of it. At the same time the insulating floor needs to cope with the loading by people and their belongings which means that it must have a certain load capacity and must be rigid in order not to reduce the amount of air included in the floor. Therefore, two approaches are feasible:

1. a rigid material which incorporates a large amount of air (e.g. high density EPS)

2. a load-bearing material which creates an insulating air layer (e.g. wooden pallet)

With respect to a post-disaster situation which is generally characterised by material and transport scarceness, both approaches are difficult to carry through. It becomes a by far more difficult task than the insulation of the tent's roof. For this an additional insulating air layer can be constructed comparatively easy by hanging an additional layer of material from the existing loadbearing elements. These encountered difficulties can be seen as one of the reasons why solutions for the insulation of the roof are already on the market while the floor has been neglected so far.

Subsequently, the different design options will be presented categorising them into building materials, miscellaneous materials and thin layer solutions. All solutions are related to the floor insulation of the new generation UNHCR tent (floor area: 3 m x 5.5 m) but adaptions to other floor dimensions are easily possible. A distinction will be made between those solutions that are suitable for the creation of a floor insulation and hence should be discussed in detail and those that have been excluded after detailed investigation. For them a condensed version with a general description and the reason for exclusion will be given. As stated above a transfer of solutions from other types of tents is not possible (see Chapter 5.6 and 5.7). For all presented options applies that, unless something different is mentioned, the insulating layer is covered on both sides by a tarpaulin. The one underneath should already be sewn into the tent, while the one on top is delivered separately. A standard tarpaulin as described above (see Chapter 5.5.4) can be deployed. Due to the daily wear and tear, attention should be payed to deliver a thick quality of tarpaulin ($> 600\ g/m^2$) if available[1].

7.2 Building Materials

The use of building materials is straight forward as a lot of insulating materials exist which are used in a way similar to disaster relief. Unfortunately, the major proportion of materials can not be considered as they are not rigid enough. This applies for example for the widely used mineral fibres. Other materials disqualify due to their high cost like vacuum insulation panels. In contrast the use of polystyrene and polyurethane foams is very promising as types with sufficient rigidity and comparatively low prices exist. Therefore, the subsequent discussion of design options will start off with these materials before concluding with two very new and innovative insulating materials i.e. Basotect and infrared reflective insulation.

7.2.1 EPS Materials

Already used as an example in Chapter 6, a floor insulation of EPS is very promising. From the production process of EPS two different options for an insulating tent floor can be derived: the use of the final product i.e. EPS plates or of the intermediate product i.e. EPS granules (see Figure 7.1). The later evolves after the pre-expansion of the basic material polystyrene. In a second expansion heat and vapour react with the pentane which is included in the basic raw material to form the final blocks of EPS[2]. As without a second expansion the pentane evaporates within a couple of days it can not negatively influence the use of the granules neither by provoking that the granules stick

Figure 7.1: EPS pearls after pre-expansion [BASF AG, a]

together nor by negative health impacts on the inhabitants[3]. Therefore, after dealing in the subsequent chapter with EPS plates the granular option will be investigated. Finally, floor options with Neopor/Lambdapor which belong to the group of EPS but are modified to improve the thermal resistance will be discussed.

7.2.2 EPS/XPS - Plates

Material Properties

Beside the already described production of EPS, polystyrene can as well be expanded to form extruded polystyrene (XPS) which distinguishes from EPS by its smaller pores. They lead to a higher compressive strength and a lower capacity to soak up with water which is both positive under the given requirements[4]. In view of the strong similarity it seems useful to discuss options incorporating XPS together with the EPS in this section.

Due to wear and tear as well as the danger of local punching the compressive strength for 10 % compression (σ_D) of both EPS and XPS is critical. As for higher densities the compressive strength increases, EPS with a minimal density of $\rho = 30\ kg/m^3$ (i.e. $\sigma_D = 200 - 250\ kPa$) and XPS of the types Styrodur 2500 C ($\rho = 28\ kg/m^3$ and $\sigma_D = 150 - 200\ kPa$) and Styrodur 3035 CS ($\rho = 33\ kg/m^3$ and $\sigma_D = 200 - 250\ kPa$) were selected. The considered average compressive strength of $\sigma_D = 200\ kPA$ corresponds to a loading of about 100 kg on an area of 0.1 m x 0.05 m which is sufficient for the given loading by persons and their belongings. This was additionally verified by punching tests on different types of Styropor and Styrodur. However, using rigid plates there is a danger that they might break due to uneven ground underneath the tent. As this does not impact

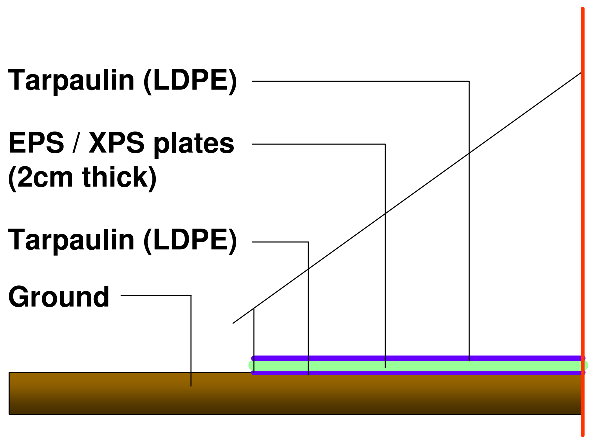


Figure 7.2: Floor insulation of EPS/XPS plates

largely on the thermal resistance of the overall floor this is not seen as a reason for excluding the presented design.

The following properties apply for all EPS/XPS products and will therefore not be repeated for the other floor designs. EPS is flame-retardant (class B1 after DIN 4102-1) and does not rot or mould. Due to its closed cell structure water can only be absorbed in small quantities in the spandrels[5].

Floor Layout

The entire floor shall be covered with plates of 2 cm thickness without grooves (see Figure 7.2). A fit with the individual size of the tent's floor can be easily provided by cutting the insulating material with a hot wire.

Thermal Resistance

With the thermal conductivity $\lambda = 0.035\ W/mK$ and a 2 cm layer of EPS/XPS the total thermal resistance of the floor layout becomes $R_T = 0.78\ m^2K/W$ which is at the lower border of the in Chapter 6.3.2 defined necessary thermal resistance.

Supply

Due to the world wide use of EPS not only in the building industry but as well in the commodity sector a regional supply within less than 200 km distance is possible[6].

- Weight: 9.9 kg
- Volume: 0.33 m^3

Dismantling

As the used insulation is a traditional building material a reuse in reconstructed houses is easily possible.

For all EPS solutions applies the following:

- *disposal* does not provoke dangerous impacts on the nature
- *burning* generates a lower toxicity than known from wood
- *recycling* is completely possible[7].

Evaluation

Due to its high thermal resistance as well as a low volume and weight the use of EPS/XPS plates is a promising design. However, attention should be drawn to the restricted resistance to local compressive impacts on both the under- and the upper side which could significantly reduce the life span.

7.2.3 EPS - Granules

Material Properties

In contrast to the before discussed use of EPS plates the deployment of its granular intermediate product overcomes the problem of a potential breaking of the plates. The granules react upon uneven ground and local punching forces by deformation and rehabilitation. However, tests on different types of granules showed that the compressive strength of the individual pearl is not as high as the one of the twice expanded material. Consequently, the granules did not only react on the impact by a reversible deformation (pearl position and volume) but as well by an irreversible volume reduction of the pearls. After a certain period of use this would clearly reduce the overall thermal resistance so that further full scale testing should investigate to which degree the volume and the thermal resistance are reduced. It shall be annotated that a reduction in thermal resistance will not be proportional to the decrease of thickness of the EPS layer. It will partially be compensated by a reduced thermal conductivity which comes along with the raised density and consequently reduced heat loss by radiation (see also 7.2.4).

The pearls of the granules feature mainly a diameter of 2 - 4 mm which is largely dependent on the original size of the polystyrol sphere and the degree of pre-expansion[8]. As the pearls are exceptionally light they easily disperse and have to be handled with care.

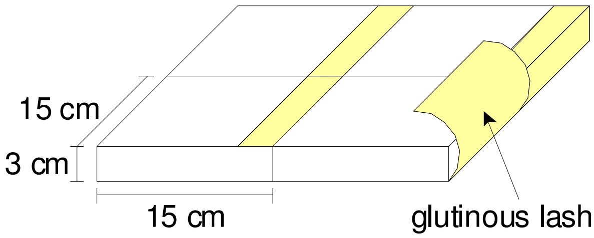


Figure 7.3: ‘Duvet’ filled with EPS granules

Floor Layout

The floor layout is basically borrowed from a duvet which consists of small cells filled with feathers. As, corresponding to the feathers in the duvet, it has to be prevented that the granules accumulate in one corner a LDPE cover with small cells of 15 cm x 15 cm shall be provided and guarantee a uniform insulating layer. The individual cell shall have a layout similar to the one of an envelope with one side open that can be closed with a glutinous lash (see Figure 7.3). This design allows for a local filling by the affected and shortens the manufacturing process. Consequently the costs are reduced and the transport is simplified as a folded cover and a bag with granules are very handy. At the initial stage the insulating layer shall have a thickness of 3 cm. Attention needs to be given to a very tight filling of the cells in order to reduce as much as possible the risk of deformation and subsequent absence of insulation in some areas.

Thermal Resistance

The thermal conductivity of granules with a density of $\rho = 15\ kg/m^3$ is $\lambda = 0.05\ W/mK$ [9]. For the initial stage of a 3 cm layer the overall thermal resistance becomes $R_T = 0.81\ m^2K/W$. As already mentioned above the volume of the pearls will reduce during use leading to a thinner insulating layer and a decrease in the thermal resistance of unknown amount. To reduce the negative effect on the thermal behaviour a refill will be useful after some time of use. This could be facilitated, depending on the transport capacities, by either delivering more granules than initially required or by additional delivery at a later point.

The EPS granules are regionally available (see Chapter 7.2.2). Moreover a use of recycled EPS would be possible. For the supply of the LDPE cover two options are feasible: the global production after a disaster or the prefabrication and storage of it which is facilitated by the small volume and the long shelf life. In some cases also a local supply might be feasible.

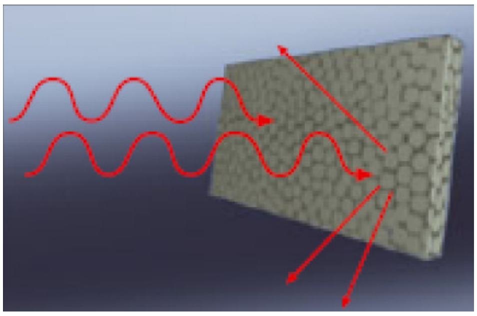


Figure 7.4: Neopor: Infrared absorbers and reflectors minimise heat loss by radiation [BASF AG, b]

- Weight of granules: 7.43 kg
- Volume of granules: 0.495 m^3

Dismantling

A reuse of the granules for permanent housing is easily possible e.g. as poured insulation or as ingredient for insulating concrete.

Evaluation

The thermal properties, the accommodation of uneven ground and local punching as well as the easy supply of the EPS granules are strong points in favour of the given design. However, the supply of the cover causes additional costs and logistical efforts in combination with the necessity to facilitate a local filling. With respect to the volume reduction of the pearls further testing is required as well as an evaluation to which degree a refill could overcome this problem.

7.2.4 Neopor / Lambdapor

General Description

Known under the brand names Neopor or Lambdapor this is a special type of EPS. It incorporates graphite giving the final product a silver-gray appearance. Its thermal properties are significantly better than those of ordinary EPS as the graphite drastically reduces the heat lost by radiation as depicted in Figure 7.4 ($\lambda_{Neopor} = 0.032\ W/mK$ for $\rho = 15\ kg/m^3$)[10]. Consequently, the thermal conductivity of low density Neopor/Lamdapor is comparable to the values which are obtained by a significant increase in density of ordinary EPS resulting in comparable thermal consequences as for the inclusion of graphite ($\lambda_{EPS} = 0.031 - 0.035\ W/mK$ for $\rho = 30\ kg/m^3$)[11].

Reason for Exclusion

Given the need for high density EPS as it provides the required compressive strength the possible reduction of density by Neopor/Lambdapor can not be exploited. At the same time a reduction in material thickness which would be the result of using higher density Neopor/Lambdapor does not seem useful as the insulating layer of EPS is already very slim and a further reduction would increase the risk of breaking the plates. Furthermore, for the same material density the price for Neopor/Lambdapor is more than 50 % higher than the one for ordinary EPS[12]. Consequently, with no advantage found the presented option is uneconomic.

7.2.5 Polyurethane - Locally Produced

General Description

Having developed the technology of locally produced spraying foam the chemical company Bayer deployed the well insulating Polyurethane (PUR) foam ($\lambda = 0.027\ W/mK$) as well in the emergency shelter sector. In 1970 after the Gediz earthquake a couple of Bayer technicians travelled to Turkey in order to produce PUR domes, also called igloos, by spraying PUR on an inflatable formwork. The well insulating emergency shelter became so beloved that after reconstruction was finished the affected moved them to their gardens where they were used as extra room for animals and storage (see Figure 7.5). However, when constructed after subsequent disasters (Peru earthquake, 1970 and Masaya earthquake, Nicaragua, 1972) the acceptance of the population was very low so that thereafter the igloos were no more produced[13].

In spite of the unsuccessful use of PUR for entire shelters, its application for an insulated tent floor exploits one major advantage of PUR: no insulating air has to be transported into the disaster region as it can be produced locally. Mixing its two liquid components polyol and polyisocyanat which thereafter react with a large volume increase the insulating foam is created. Consequently the transport volume would be very small. Transporting the two liquids in barrels on a small lorry the floor insulation could be produced e.g. by spraying it on a tarpaulin wherever it is demanded. For this work qualified personal would be needed in order to produce an even layer and to be able to maintain the spraying equipment. A second option for the production of locally foamed PUR would be the use of spray cans which could be distributed to the affected and allow them to foam up their own floor insulation.

Reason for Exclusion

After consultations with SDC/HA (Swiss Agency for Development and Cooperation/Humanitarian Aid) the first option of collectively produced PUR had to be

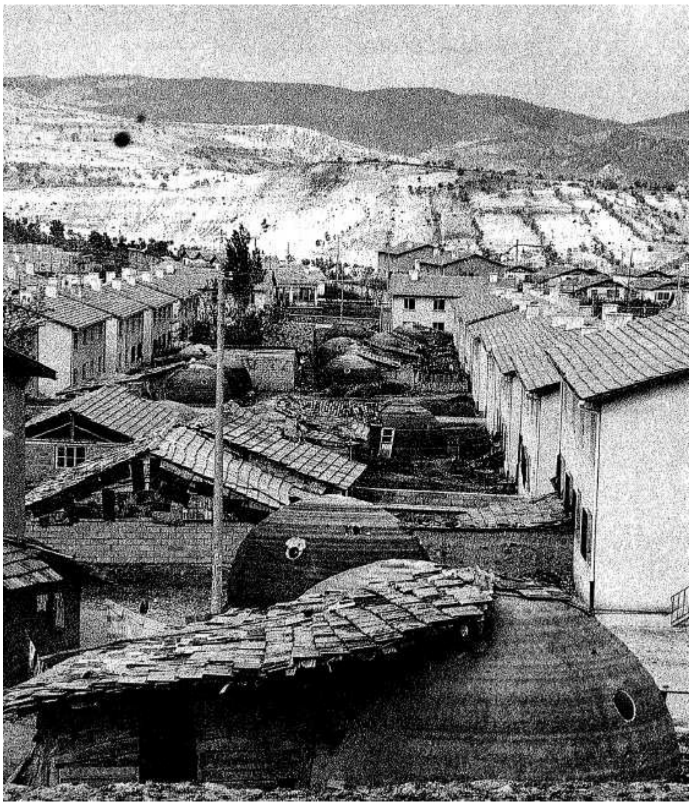


Figure 7.5: PUR domes in the back gardens of reconstructed homes [Özkan, 1983]

excluded as given the disaster relief situation it is doubtful that a local production of even foam floors would be possible[14].

Keeping in mind the obstacles for the first production method the second option, i.e. the use of spray cans features additional reasons for exclusion as for one floor of 3 m x 5.5 m produced with a thickness of 2 cm 8 spraying cans of 750 ml liquid each would be necessary[15]. Due to the large number of required cans and the subsequently needed disposal this solution is certainly not sustainable. A further negative point is the high cost of the cans while it has to be positively noted that this option would be less labour intensive as the foaming can be carried through by the affected themselves[16].

7.2.6 Polyurethane - Centrally Produced

General Description

Having considered so far the local production of PUR the second option would be to manufacture it centrally and deliver the ready foam into the disaster region.

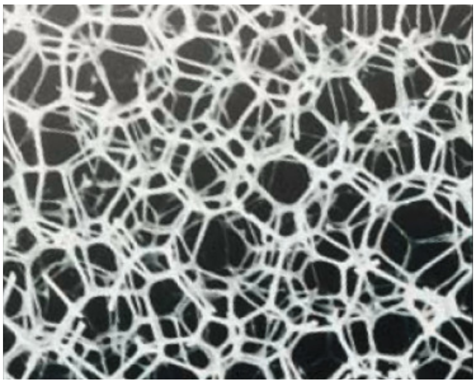


Figure 7.6: Scanning electron microscope picture of Basotect [BASF Plastics, 2006]

This would overcome the difficulty of local production at the cost of a largely increased transport volume.

Reason for Exclusion

Even though the thermal conductivity of PUR is lower than the one of comparable foams like EPS ($\lambda_{PUR} = 0.025\ W/mK$, $\lambda_{EPS} = 0.035\ W/mK$) its deployment is not reasonable as the advantage in thermal conductivity is exceeded by the significantly higher prices for PUR. For comparable density and compressive strength the price per square meters is more than 1.8 times the price of EPS[17].

7.2.7 Basotect

General Description

Basotect is a relatively new and very innovative foam of BASF with excellent insulating properties. Although the use has so far been restricted to other areas like planes, acoustic panels etc. an application for thermal insulation of buildings is foreseen. The excellent thermal insulation of the melanin foam derives from its structure which is formed by very slender rips in an open-cell foam (see Figure 7.6). The scarceness of solid material reduces the heat lost by conduction while the fineness of the pores minimises convective heat losses, resulting in a thermal conductivity of $\lambda < 0.035\ W/mK$ [18].

Reason for Exclusion

In spite of the very promising thermal properties, Basotect has to be excluded for a couple of reasons. To name only two its firstly too expensive with a price of about five times the one of EPS and secondly not durable enough as it crumbles under compression[19].

7.2.8 Infrared Reflective Insulation

Thermal Properties

Infrared (IR) reflective insulation is a very new and innovative insulation material for buildings. Considering the three mechanisms of heat transfer (i.e. conduction, convection and radiation, see Chapter 6.3.1) it insulates by reducing the heat lost by radiation. This distinguishes it from usual insulating materials which mainly aim to reduce the heat lost by conduction[20]. The principle of reflective insulation is based on reducing the heat exchange between two surfaces of different temperatures by reducing the emissivity ϵ of the surfaces. From this the alternative declaration as 'low-ϵ' materials derives[21]. Referring to Equation 6.4, i.e. $q = \epsilon \cdot \sigma \cdot T^4$ it becomes apparent that for a reduction in ϵ from 0.9 (usual building materials) to 0.1 (low-ϵ materials) a significant decrease in the heat loss q is gained. Considering the example of a 5 cm horizontal air layer with non metallic surfaces, a downwards directed heat flux and a temperature decrease from 10 $°C$ to 0 $°C$ only 10 % of the heat flux is attributed to convection and 90 % to radiation[22]. The example clearly indicates the great potential in improving the insulating capacity of air layers by reflective materials. It should be kept in mind that heat losses by radiation can only occur if two surfaces are seperated by an air layer or vacuum which significantly restricts the use of this type of insulation.

Advantages

The major advantage of these materials is that they do not aim to reduce conductive heat losses but radiative: while conductive insulation materials require a large proportion of well insulating air and hence are very bulky, radiative insulation is attributed to a different material surface and hence an insignificant increase in volume. In contrast to the standard reflective insulation which is composed of several reflective layers and thin layers of materials with a large air content like bubble wrap (see Figure 7.7) here only single layers of reflective foil will be considered. These can be manufactured by applying a metallic coating to standard tarpaulins. Given the restricted transport possibilities in post-disaster situations the great potential of reflective insulations is instantaneously apparent.

Application

As the applicability of low-ϵ materials necessitates the existence of an adjacent air layer it can not be deployed for solid insulating layers. Furthermore, aluminium foils shall not be applied to surfaces directed towards a living room as this leads to an uncomfortable atmosphere within the tent. This is additionally sensible with respect to the drastically raised danger of condensation on the inner tent surface as the heat-transmission resistance R_{si} would significantly increase and with it the

Figure 7.7: Reflective insulation with multiple layers [Proceedings of 4. Fachseminar, 2007]

temperature gradient towards the inner tent surface. Consequently, the following possibilities for the application of infrared reflective foils/coatings exist:

1. improve thermal resistance of existing air layers either within floor or between different layers of roof
2. reduce heat loss to sky during night by reflective outer shell.

The application to different floor designs will be included in those layouts that provide an air layer. For the use in tent roofs it shall be referred to Chapter 8.3.

Determination of Thermal Properties

After DIN EN ISO 6946 the heat-transmission resistance at the surface of a component (R_{si}/R_{se}) and the thermal resistance of air layers can be calculated for different emissivities ϵ [23]. Therefore, this code shall be applied for all components incorporating infrared reflective layers using an emissivity of $\epsilon = 0.1$. In spite of the ongoing discussion about a possible increase of the emissivity during the long service life of building materials e.g. by pollution, in the given context the assumption of $\epsilon = 0.1$ is certainly justifiable due to the comparatively short usage of emergency shelters[24]. Generally it has to be annotated that due to the novelty of this type of insulation a lot of different assessments of their thermal behaviour exist and that a uniform standardisation will continue to be discussed controversially.

7.3 Miscellaneous Materials

7.3.1 Introduction

Beside the use of insulation materials known from the building industry, certainly other options for the formation of an insulated tent floor exist. One of these is the creation of an air layer by a load-bearing construction for which two layouts will be presented in this chapter. Both options will be additionally optimised by the before mentioned use of infrared reflective foils. The third floor option presented here will consist of straw which strictly speaking is as well a building material. However, due to its rare use for this purpose it shall be primarily regarded as a locally available material which is exploited for the given context.

7.3.2 Timber Forklift Pallets

Material Properties

In correspondence with the suggestions arising from thermal tests on a winterised tent prototype by the Shelter Centre the use of timber forklift pallets has been investigated with a specific focus on the thermal properties[25]. Timber forklift pallets are used all over the world to transport goods and exist in various dimensions. E.g. euro-pallets have a size of 800 x 1200 x 144 (B x L x H in mm) and non-returnable pallets of 800 x 1400 x 134 [26]. All of them have in common that they create with a certain distance to the ground a loadable surface. As the here considered pallets are of timber they are easily inflammable and do rot. Therefore, precautions against the impact of fire and moisture have to be undertaken.

Floor Layout

Ideally, the entire floor shall be covered by pallets. However, as the standard size of tents (3 m x 5.5 m) does not necessarily conform with the size of pallets (often 0.8 m x 1.2 m, see above) saws should be provided to facilitate the partial use of pallets. Given the predominant availability of pallets with large gaps between the top boards (see Figure 7.8) additional local adaptions are required. A continuous upper surface has to be created by either filling the gaps between the top boards with additional boards or by covering the entire pallet with a continuous plate. In the rare case of pallets with either only small gaps between the top boards or a continuous top layer e.g. of plywood these efforts become redundant.

Thermal Properties

In order to obtain conservative values for the achievable thermal resistance of the floor layout a low overall height of the pallet and consequently a small thickness of the air layer and the top boards together with a thermal conductivity of timber at

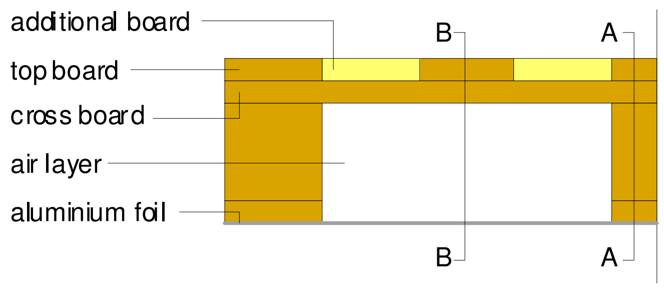


Figure 7.8: Construction of floor insulation with timber forklift pallet

the upper boundary have been considered. Therefore, the dimensions of a single use pallet with an overall height of 134 mm, a thickness of the air layer of 116 mm and of the top boards of 18 mm together with $\lambda_{timber} = 0.18\ W/mK$ have been used[27]. The thermal resistance has been determined for a cross-section formed by an air layer and a top board which again can be justified by being conservative: For the neglected cross-sections with cross boards (see Figure 7.8, section B) a higher thermal resistance is obtained as the thermal resistance of the thinner air layer does not change significantly while the one of the thicker timber layer increases largely. Furthermore, the ignored cross-sections consisting uniformly of timber (see Figure 7.8, section A) have no significant influence on the thermal behaviour as they represent only 6 % of the pallet area. In addition to the before mentioned floor design the usage of an aluminium foil underneath the pallet is suggested with the aim to minimise the radiative heat loss of the air layer (see Chapter 7.2.8).

The thermal properties of the air layer are determined after DIN EN ISO 6946 [28]. For an air layer of 116 mm without infrared reflective materials the thermal resistance is calculated to $R = 0.25\ m^2K/W$. Deploying one infrared reflective surface and hence changing the emissivity the thermal resistance becomes $R_{IR} = 1.30\ m^2K/W$ which represents a significant increase. Adding the thermal resistance of the top board ($R = 0.1\ m^2K/W$) the thermal resistance of the pallet becomes $R = 0.35\ m^2K/W$ resp. $R_{IR} = 1.40\ m^2K/W$.

Supply

Due to the wide use of pallets it can be assumed that a regional procurement will be feasible. In view of the large transport volume and weight this is certainly necessary for facilitating a solution with pallets. Even under the boundary condition of regional supply it shall not be neglected that large transport capacities are required. Considering the standard tent floor area of 3 m x 5.5 m, $3\frac{1}{2}$ x $4\frac{1}{2}$ pallets are necessary to cover the floor. Consequently the transport volume gets 2.57 m^3 and the weight about 400 kg [29]. Additionally, the availability and transport options for the material eventually required for the construction of a continuous upper surface need to be investigated. For the aluminium foil an external supply should be planned.

Dismantling

For the dismantling of the timber pallets various options without negative impact on the environment exist:

- reuse of returnable pallets
- reuse of timber for reconstruction
- use as fire wood
- composting.

Points 2 to 4 also apply for the additionally required timber. For the aluminium coated tarpaulins a reuse seems feasible.

Evaluation

Under the condition of regional availability of firstly pallets including additionally required timber and secondly transport capacities this option is very promising. In conjunction with the deployment of aluminium foil it becomes a solution which guarantees thermal comfort even for very low temperatures.

7.3.3 Modular Plastic Floor Tiles

Material Properties

In various sectors modular plastic floor tiles are used to create a temporary floor for tents (see Figure 7.9 and 7.10). Usually made of polypropylene (PP) or HDPE the tiles of varying dimensions and forms (e.g. rectangle or hexagon) can be easily connected. They create a floor surface within a distance of 2 cm of the ground and consequently provide an insulating air layer. In spite of the availability of a number of different products the following changes are suggested to adapt the existing products to the given context:

1. **Increase thermal resistance**
   As already described in the previous chapter the thermal performance of an air layer can be significantly improved by deploying for one of the two adjacent surfaces a low emissivity material. For a tile of 2 cm height this leads after DIN EN ISO 6946 to an increase of the thermal resistance from $R = 0.2\ m^2K/W$ to $R_{IR} = 0.59\ m^2K/W$ [30]. The required aluminium surface could either be an aluminium foil underneath the tiles or an aluminium coating applied to the underside of the tiles's top plate which would widen the usability of the tiles.

Figure 7.9: Modular rollable flooring system of Composystem TM [Composystem TM, 2007]

Figure 7.10: Plastic grid footboards of tent manufacturer Ferrino [Ferrino & C. S.p.A., 2007]

2. **Reduce transport volume**
   In order to reduce the transport volume it is desirable to facilitate stackability by a design which allows to interlock the bars of two tiles. For this purpose the bars, on which the top plate of the tiles rests, have to be manufactured with small gaps, into which the bars of another tile interlock (see Figure 7.11). Consequently the transport volume can be reduced by nearly 50 %.
3. **Reduce weight**
   So far most of the offered tiles are designed for a much higher loading than the one expected in family tents. Therefore, it should be feasible to reduce the amount of statically required material and consequently the weight of the tiles.
4. **Accommodate uneven ground**
   Tests should be carried out to investigate to which degree the given forms

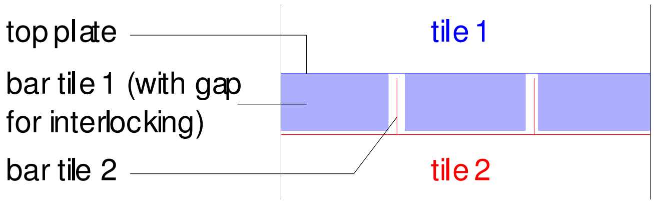


Figure 7.11: Stackability of plastic floor tiles

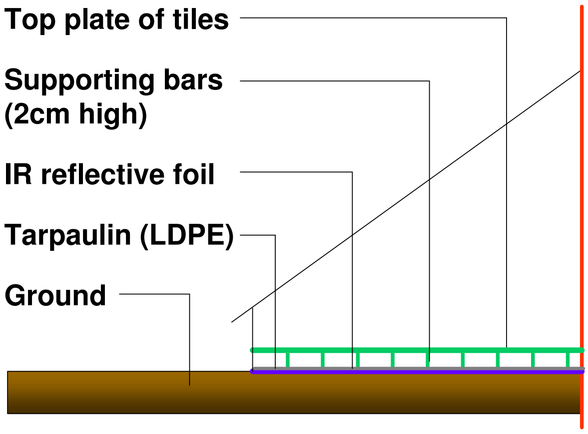


Figure 7.12: Floor insulation of modular plastic tiles

and sizes of tiles can accommodate by their hinged connections the uneven ground conditions of usual tent locations.

Returning to the material properties of the actually available tiles it shall be noted that as the tiles are made of PP or LDPE they are flame-resistant (B2) as well as resistant to moisture, mold and fungus[31].

Floor Layout

The entire tent floor shall be covered by connected tiles which are deployed on top of an aluminium foil assuming that the design of the tiles has not been enhanced by an aluminium coating (see Figure 7.12). In the case of supplying tiles with openings in the top plate (see Figure 7.10) an additional cover is required e.g. by a tarpaulin to create a closed insulating air layer.

Thermal Resistance

As given above the thermal resistance of 2 cm high tiles with one infrared reflective surface is, neglecting the insignificant thermal resistance of the plastic of the top plate, $R_{IR} = 0.59\ m^2K/W$.

Supply

Assuming for example the use of tiles as provided by the Italian tent manufacturer Ferrino (see Figure 7.10) covering a 3 m x 5.5 m tent floor results in a tile volume of 0.51 m^3 and a weight of 66 kg [32]. Executing the above suggested modification for stackability and hence a volume reduction of nearly 50% the transport volume becomes significantly lower than the one for traditional insulating building materials with a comparable thermal preformance e.g. 2 cm thick EPS. However, this advantage comes along with a significantly higher weight.

Regarding the nowadays available type of tiles the supply situation is characterised by immediate, global availability. The same applies to the additionally required aluminium foil.

Dismantling

Given the specific design of the tiles for the given purpose a reuse is unlikely so that they have to be recycled or disposed.

Evaluation

From the performance based point of view this is certainly a good option which therefore in the future will be used as flooring for the new community shelter of SDC/HA[33]. However, as it is a comparatively high-tech solution constrains for the availability both with respect to the location and the number of units arise. Additional negative consequences are relatively high costs and the before mentioned problem of disposal. Nevertheless, considering the above proposed adaptions it can be a good solution under certain post-disaster conditions.

7.3.4 Straw

Material Properties

Apart from arctic regions straw is available in all parts of the world and hence, given its good thermal performance, a good local option for the provision of a floor insulation[34]. Its thermal behaviour is characterised by the air inside the stalks and the air contained in the hollow space between the stalks. Considering the durability of straw it has to be made sure that it is dry when installed as floor insulation and that it remains dry during use which is guaranteed by an upper and lower cover with tarpaulins. With respect to an endangerment by insects and rodents it has to be clarified that straw consists of cellulose which can only be digested by termites. Hence, provided a low content of other materials within the straw, e.g. corn which is attractive to mice, the durability of the straw is not endangered by pests[35]. Straw bales are categorised as inflammable (class B2 after DIN 4102-1)[36].

Floor Layout

A major problem using straw is to ensure that under daily wear and tear no large displacements within the straw layer occur and hence the thickness of the straw layer does not partially fall below a certain minimum value. This problem is best solved using compressed straw as present in straw bales. These are produced by straw balers which are available in most parts of the world. Analysing the spread of straw balers in more detail, it can be assumed that they are used in all locations where tractors are available i.e. in all highly developed countries[37]. For their availability in developing countries it shall be referred to Figure 7.13 in which the presence of straw balers can be identified by bluish colors while for all other countries, using either man power or draught animal power (DAP), their availability is not likely.

Using cuboid straw bales an insulating layer can be created by unlacing the bales and separating the about 10 cm thick layers in which the bales are pressed by the straw balers[38]. Fixing the separated layers by new laces and covering the entire floor with them a comparatively stable insulating layer is created which adding the upper and lower cover of tarpaulin constitutes the floor layout. Given this layout uneven ground can be accommodated.

Thermal Resistance

Due to the way in which straw bales are manufactured the heat flux through the floor occurs perpendicular to the orientation of the stalks, resulting in a thermal conductivity of $\lambda = 0.052\ W/mK$ [39]. For the 10 cm thick layer of straw the thermal resistance becomes $R = 1.92\ m^2K/W$ which, due to the comparatively large thickness and the low thermal conductivity, is the highest value of all regarded solutions. Given the daily wear and tear it has to be assumed that the thickness of the straw layer is going to reduce as the straw starts to crumble. However, as this implies that the density of the straw layer increases and consequently the thermal conductivity reduces any effect on the thermal resistance shall not be further regarded[40].

Supply

As mentioned before a local supply should be possible. Consequently, the transport of the large volume of straw (1.65 m^3 for a floor of 3 m x 5.5 m) is no obstacle. Considering the distribution afoot the total weight of 165 kg significantly exceeds the weight requirements.

Dismantling

After the use as floor insulation the straw can be employed for its originally intended purpose.

Evaluation

The use of straw is certainly a valuable solution due to its local availability, low cost, reusability and good insulating capacity. However, it should be kept in mind that a considerable amount of engagement of the affected is required both for a distribution on foot and for the rebinding of the bales.

7.4 Thin Layer Solutions

7.4.1 Introduction

In contrast to the before presented floor options with a thickness of a couple of centimetres, the options of this chapter will have thicknesses of a couple of millimeters and hence are termed thin layer solutions. Consequently, their thermal resistance is much lower and by far not sufficient for the provision of an appropriately insulated floor. Nevertheless, these options merit consideration as they are definitely better than no insulation at all and hence an understanding of their benefits and shortcomings is certainly helpful.

One straightforward option for a thin layer insulation is the reuse of cardboard boxes in which relief items are delivered (see Figure 7.14). Furthermore, an insulating layer of bubble wrap or closed cell foam acoustic floor mats will be investigated. Apart from the bubble wrap the options shall be deployed without an upper cover of tarpaulin.

All three options feature a high air content and consequently a low thermal conductivity. This, however, can not be exploited to obtain a high thermal resistance as the thickness of all three options is below 5 mm. Evaluating the thermal performance the judgment is ambiguous: Considering the solution with the highest thermal resistance, i.e. a 5 mm acoustic floor mat with $R = 0.125\ m^2K/W$ (see Chapter 7.4.4) and $R_T = 0.335\ m^2K/W$ (see Chapter 6.3.2) the heat loss through the tent floor ($A = 16.5\ m^2$) for a temperature difference of 30 $°C$ ($T_i = 20\ °C$, $T_e = -10\ °C$) becomes $Q = 1478\ W$ and $T_s = 4.78\ °C$. Compared to a heater output of 5 - 7 kW the heat loss (Q) is too high and the surface temperature (T_s) is too low for thermal comfort. Hence, for the longer term the thermal performance is insufficient. On the other hand, regarding the prevention of excessive heat loss from the body, even the solution with the lowest thermal resistance, i.e. the corrugated cardboard with $R = 0.05\ m^2K/W$ (see Chapter 7.4.2) reduces the heat loss of persons sitting or laying on the ground by 40 % assuming that the persons are fully dressed ($R_{cloth} = 1\ Clo$) and that the thermal resistance of the clothing is halved under the compression of the body weight (see Chapter 8.2.3). In view of the potential risk for health and even life due to chill this is a valuable improvement.

To assess the potential of thin layer solutions the list of advantages and disadvantages given in Table 7.1 is helpful. It can be concluded from it that thin layer insulations can be classified as first, interim solutions.

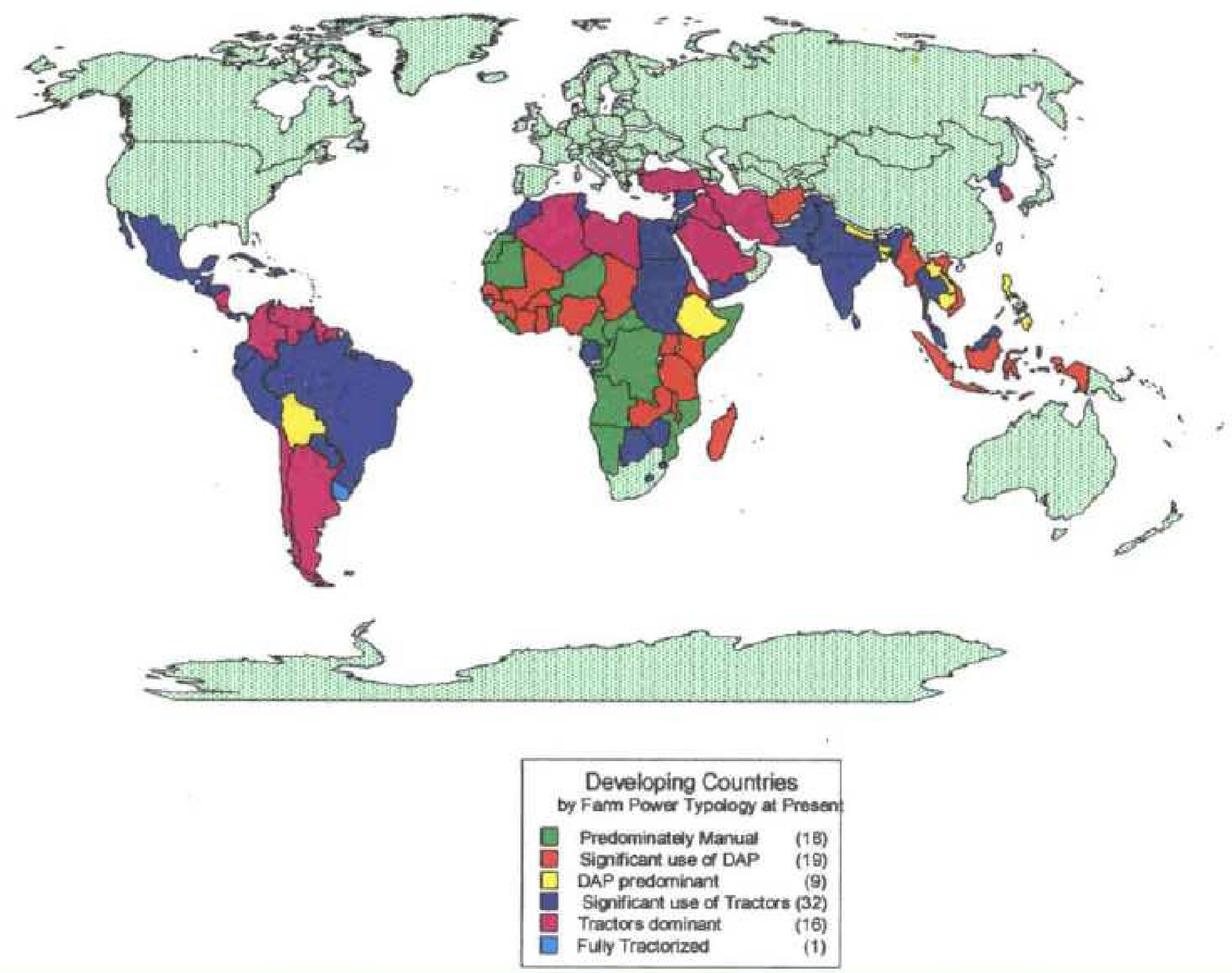


Figure 7.13: Farm power typology of developing countries as of 2002 [Clarke, 2002]

Advantages	**Disadvantages**
some insulation	insufficient insulation
low volume/weight	low durability
low cost	easily inflammable
flexible (accommodation of uneven ground)	

Table 7.1: Advantages and disadvantages of thin layer solutions

Figure 7.14: Affected of the Jogyakarta earthquake sitting on cardboard [Humanitarian Centre ‘Jogya Bangkit’, 2006]

Figure 7.15: Corrugated cardboard [FEFCO, 2007]

7.4.2 Cardboard

General Description

As immediately after a disaster many relief items are delivered in cardboard boxes (e.g. hygiene and kitchen kits) cardboard, at least for a partial cover of the tent floor e.g. to sit on it, is available. Even though the thermal conductivity of paper is higher than the one of standard insulating materials ($\lambda = 0.18\ W/mK$ [41]), corrugated cardboard of which cardboard boxes are made has a good thermal performance due to the air enclosed in its corrugated middle layer (see Figure 7.15). The thermal resistance of 2.5 mm thick corrugated cardboard is $R = 0.05\ m^2K/W$ [42]. As no data on the actual thermal behaviour of cardboard boxes is available this value shall be taken. It certainly represents a conservative assumption as, given the weight of the package's content, the utilized cardboard should be thicker ($\approx 3 - 4\ mm$).

Pros and Cons

The shortcomings of this solution are clearly the degradation of wet cardboard and its comparatively low resistance to the impact of daily wear and tear. A danger

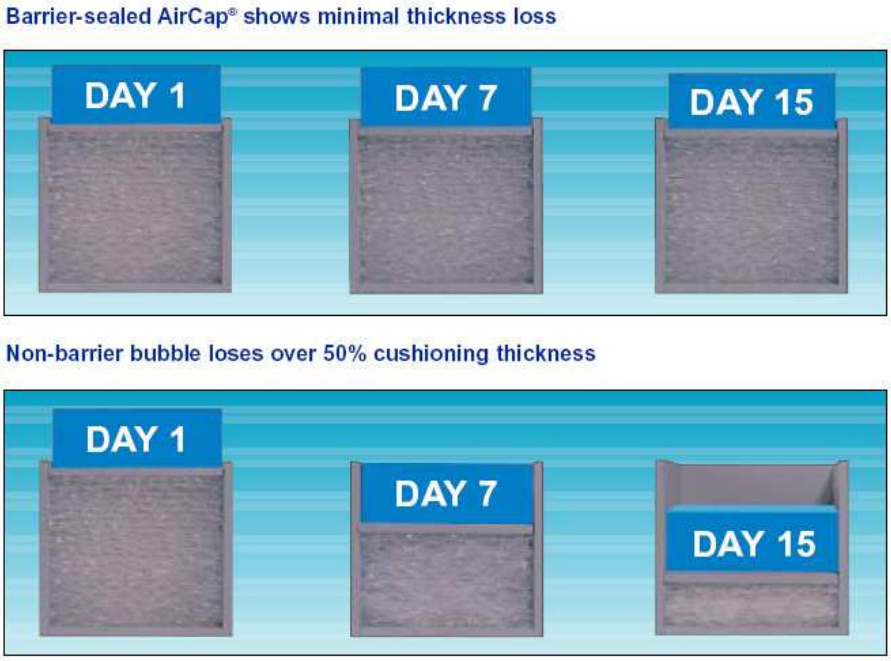


Figure 7.16: Decrease in thickness of bubble wrap under 2.068 kPa loading

has to be seen in the fact that it is easily inflammable. Strongly in favour of this solution is its use of material that is otherwise disposed and the ease of recycling after its usage in the tents.

7.4.3 Bubble Wrap

General Description

Bubble wrap is sold with uncountable bubble diameters and heights. For simplicity here the example of AirCap CS bubble wrap with a bubble diameter of 9.5 mm and a bubble height of 4.2 mm will be regarded. It was selected as it offers a good air retention and is designed for comparatively high loading[43]. It represents a cheap (0.43 €$/m^2$) and light ($\approx$ 40 g/m^2) option for the floor insulation[44]. Supplied on rolls of e.g. 50 m^2 it can provide a floor insulation for a couple of tents. Considering a thermal conductivity of $\lambda = 0.04\ W/mK$, which in view of the predominant air content ($\lambda_{air} = 0.026\ W/mK$ [45]) is certainly a conservative value, a thermal resistance of $R = 0.105\ m^2K/W$ is obtained.

Pros and Cons

A definite problem of bubble wrap is its loss of air and consequently insulating

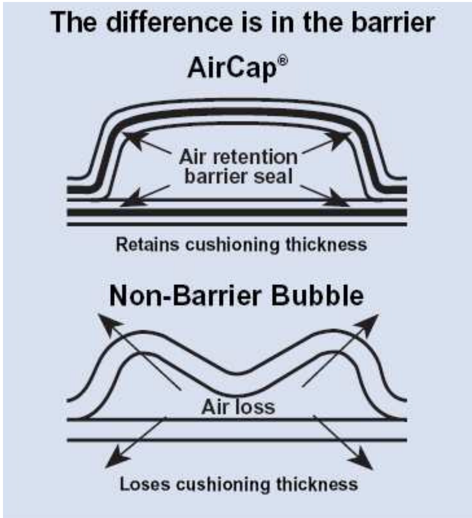


Figure 7.17: Air loss of bubble wrap [Sealed Air Cooperation, 2006]

capacity under loading (see Figure 7.16). Even though bubble wrap with an air retention barrier as considered here might be supplied (see Figure 7.17) and the in Figure 7.16 given loading of about 2 kPa will not be constantly applied to the tent floor, its life span is certainly limited. In order to reduce the potential air loss it is additionally of importance to select bubble wrap which is designed for high loading as given in the here discussed example. To minimise the danger of piercing the bubble wrap it is sensible to protect its upper surface by a tarpaulin. As bubble wrap is made from polyethylene (PE) it is easily inflammable but resistant to moisture, mold and fungus. It can be either energetically recycled or disposed with domestic waste without being toxic[46].

7.4.4 Acoustic Floor Mats

General Description

Acoustic floor mats of closed cell, extruded polyethylene foam are widely used in the building industry for the sound insulation of floors. As before the bubble wrap it is cheap (0.76 €/m^2), light (110 g/m^2) and suppliable on rolls (e.g. of 100 m^2)[47]. The standard thicknesses are up to 5 mm for which a thermal resistance of $R = 0.125\ m^2K/W$ is measured[48].

Pros and Cons

As the closed cell foam is made of the same material as the bubble wrap, it shall be referred to the pros and cons listed with respect to PE in the previous chapter (7.4.3).

7.5 Thermal Benefits of Floor Insulation

Having discussed in detail various options for a floor insulation the subsequent chapter will evaluate the thermal benefits gained by a floor insulation. For this purpose a comparison of the absolute values describing the thermal performance e.g. the overall heat loss through the floor will be made between two exemplary floor options (EPS/XPS plates and plastic floor tiles) and the basic and advanced winterisation as described in Chapter 4.5.5. Additionally, for the heat loss during sleeping a comparison with standard camping equipment will be made.

For the evaluation of the thermal benefits five criteria have been defined based on the results of Chapter 6.3 (Calculation Method for Heat Transfer through Floor) and Chapter 8.2 which will investigate in detail the required bedding in cold climate disaster regions:

1. **Total thermal resistance (R_T)**: For a reasonable insulation the thermal resistance has to be limited both to the upper and the lower bound (see Chapter 6.3.2).

   Requirement: $0.8\ m^2K/W \leq R_T \leq 1.1\ m^2K/W$

2. **Heat loss during sleeping (Q_{sleep})**: To avoid chilling during sleeping the heat loss from the body to the ground and the surrounding air has to be limited.

   Requirement: $Q_{sleep} \leq 85\ W$

3. **Overall heat loss through floor (Q_{floor})**: In order to gain thermal comfort within the tent the heat lost through its boundaries should not exceed the heat produced by the stove (5 - 7 kW) and hence the heat loss through the tent floor should be limited.

   Requirement: $Q_{floor} \leq 1000\ W$

4. **Surface temperature of floor (T_s)**: A lower bound should be respected for the surface temperature of the floor in order to gain thermal comfort.

   Requirement: $T_s \geq 15\ °C$

5. **Percentage of dissatisfied (PD)**: Beside the calculable changes of the thermal properties the PD allows for an evaluation of the raised thermal comfort as perceived by the tent occupants. Given this function of the PD a requirement shall not be defined but the value be used for a final judgment of the efforts undertaken in fulfilment of the previous requirements.

Based on these five criteria Table 7.2 compares the different options for a ground temperature of $-10\ °C$ and an internal tent temperature T_i that varies corresponding to the most likely conditions of each regarded criteria as follows:

	T_i	**Basic winter-isation**	**Advanced winter-isation**	**EPS/ XPS plates**	**Plastic floor tiles**	**Camping equipment**
Standard		2 tarpaulins, 3 blankets				–
Addi-tions		–	mattresses, stove	2 cm EPS/XPS, stove	2 cm high tiles, stove	sleeping bag, self-inflating mat
R_T		0.21 m^2K/W	2.43/0.21 m^2K/W	0.78 m^2K/W	0.80 m^2K/W	
Q_{sleep}	$-10/$ $12\,°C$	138 W	41 W	59 W	59 W	60 W
Q_{floor}	$20\,°C$	2344 W	1513 W (79/1434 W)	633 W	622 W	
T_s	$20\,°C$	$-4.1\ °C$	$18.0/-4.1\ °C$	$13.5\ °C$	$13.6\ °C$	
PD	T_s	86.2 %	12.9/86.2 %	26.8 %	26.4 %	

Table 7.2: Thermal properties of different floor options

- Q_{sleep} → $T_i = -10/12\ °C$ external air temperature resp. temperature reached by diminished heating during night and large stratification towards the ground for options with stove
- Q_{floor} → $T_i = 20\ °C$ temperature reached by heating the tent
- T_s → $T_i = 20\ °C$ temperature reached by heating the tent
- PD → $T_i = T_s$ surface temperature as calculated above

To measure Q_{floor} and T_s a temperature gradient between the inside of the tent and the ground is required so that these values were calculated for all options with a heating stove ($T_i = 20\,°C$) even though a stove is not included in the basic winterisation package. Beside the camping equipment option all other options deploy two layers of tarpaulin for the ground insulation and three high thermal resistance blankets for the personal insulation during sleeping (see also Chapter 8.2)[49]. The camping equipment consists of an average sleeping bag with the specification to provide comfort down to $-30\ °C$ and a self-inflating mat for down to $-10\ °C$ ($R = 0.6\ m^2K/W$)[50]. For the advanced winterisation it is distinguished between the area covered by mattresses (6.4 m^2) and the one without mattresses by giving two values where applicable.

From the results given in Table 7.2 it can be concluded that the developed options for the floor insulation provide a thermal comfort during sleeping which is comparable to the one of camping equipment. Comparing the developed options furthermore with the basic winterisation, it can be seen that the overall heat loss from the tent can be

Min. temperature	$10\ °C$	$5\ °C$	$0\ °C$	$-5\ °C$	$-10\ °C$	R_T
EPS/XPS plates	$\surd$	$\surd$	$\surd$	$(\surd)$	$(\surd)$	$0.78\ m^2K/W$
EPS granules	$\surd$	$\surd$	$\surd$	$(\surd)$	$(\surd)$	$0.81\ m^2K/W$
Pallets without IR reflection	$\surd$	$\surd$	$(\surd)$			$0.56\ m^2K/W$
Pallets with IR reflection	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$1.61\ m^2K/W$
Plastic floor tiles	$\surd$	$\surd$	$\surd$	$(\surd)$	$(\surd)$	$0.80\ m^2K/W$
Straw	$\surd$	$\surd$	$\surd$	$\surd$	$\surd$	$2.13\ m^2K/W$

Table 7.3: Floor options depending on local climate

reduced drastically while the surface temperature raises significantly. This finally results in a 69 % reduction of the percentage of dissatisfied. Having a look at the advanced winterisation the advantages of an insulation for the entire floor become apparent. While the areas covered by mattresses perform very well with e.g. Q_{sleep} being much smaller than the values obtained for the camping equipement, the overall balance as given e.g. by Q_{floor} is clearly in favour of the developed options. Therefore, it can be concluded that, investing in additional goods for the floor insulation, a thin cover of the entire floor is more efficient than the nowadays practice of local insulation by mattresses. Comparing the results with the previously defined requirements, it can be seen that apart from the surface temperature the developed options fulfil all requirements. In contrast, the basic winterisation satisfies none of the criteria and the advanced winterisation only the one for Q_{sleep}.

7.6 Tool for Selection of Floor Options Depending on Local Climate

Table 7.3 represents an easy to apply tool which can be used by people engaged in disaster relief to select an appropriate floor option in dependence on the climate within the disaster region. The therefore necessary information on the local climate will be made available by UNOSAT which after a disaster provides maps with e.g. monthly mean temperatures or land surface temperatures (see also Chapter 4.5.3 and Appendix B, Figure B.1 and B.2). Developing the tool, the determination of the minimal temperature for appliance of the given options has been based on the five requirements of the previous chapter. Comparing the four explicitly defined criteria (number 1 - 4) the requirement for the surface temperature is the most critical so that the given table is based on the fulfilment of the requirement $T_s \geq 15\ °C$ (indicated by $\surd$). This means that at the same time for Q_{sleep}, Q_{floor} and PD governs:

$$Q_{sleep} \leq 55.1\ W \qquad Q_{floor} \leq 485\ W \qquad PD = 21.4\ \%$$

As in disaster situations with limited resources available the requirement $T_s \geq 15$ °C might be too strict a second, lower boundary with $T_s \geq 13.5$ °C (indicated by ($\surd$)) was introduced. Although this can not be seen as a comfortable solution, it leads to a percentage of dissatisfied of about 25 % which under certain conditions is acceptable. This second boundary implies:

$$Q_{sleep} \leq 59.4\ W \qquad Q_{floor} \leq 633\ W \qquad PD = 26.8\ \%$$

The results for all floor options which have previously been judged feasible are summarised in Table 7.3. The thin layer solutions have been excluded as they can only be seen as a last resort and the fulfilment of thermal comfort shall not be misleadingly suggested by including them. The table demonstrates that beside the pallets without IR reflection all options can be deployed up to -10 °C. For both solutions using EPS/XPS and for the plastic floor tiles, however, the concession of a surface temperature below 15 °C has to be made for temperatures below 0 °C.

To finally evaluate the developed options with respect to the thermal comfort perceived by the occupants it has to be noted that a reduction in the percentage of dissatisfied of 75 % for $T_s = 15$ °C resp. 69 % for $T_s = 13.5$ °C as compared to the basic winterisation by two tarpaulins could be gained. This clearly underlines the potential of the developed solutions.

7.7 Summary of Fulfilment of Requirements

To conclude the discussion of the developed floor options the three subsequent tables summarise the fulfilment of the requirements as presented in Chapter 6.2 for all options judged applicable including the thin layer solutions. In correspondence with the above approach, separate tables for the requirements from function (Table 7.4) and the requirements from context (Table 7.5 and 7.6) are given. In Table 7.4 and 7.6 the degree to which each requirement is fulfilled, is indicated by - / + / ++ given in the order of increasing fulfilment. In contrast to this, a different depiction became necessary for those context requirement criteria, for which different options have been identified in Chapter 6.2.2. In Table 7.5 a $\surd$ indicates that the corresponding requirements of a specific option are fulfilled and hence, depending on the given disaster context, a certain floor option might be favourable or not. An exception to this depiction is made for the cost, for which in Chapter 6.2.2 four different options depending on the boundary conditions of the delivery time/availability and the origin/transport have been elaborated. In order to avoid duplicating the results already given for the corresponding requirement criteria, it has been opted to indicate the degree to which the necessity of low cost, distinguishing between material, transport and storage cost, is satisfied. It has to be pointed out that, as a low cost is the best, this is eventually misleadingly indicated by ++. Within the column for storage costs no entry is made as none of the regarded solutions requires the

Floor Option	impermeable to water	rot-proof	frost-resistant	flame-resistant	heat-resistant	resistant to wear and tear	rigid (on top surface)	slightly flexible (on bottom surface)	no air loss by piercing	indestructible by vermins
EPS/XPS plates	++	++	++	+	+	+	+	-	++	++
EPS granules	++	++	++	+	+	+	+	++	++	++
Pallets without IR reflect.	++	-	++	-	++	++	++	+	++	-
Pallets with IR reflect.	++	-	++	-	++	++	++	+	++	-
Plastic floor tiles	++	++	++	-	+	++	++	++	++	++
Straw	+	-	++	-	++	+	+	++	++	+
Cardboard	-	-	++	-	++	-	+	++	++	+
Bubble wrap	++	++	++	-	+	-	-	++	+	++
Acoustic floor mats	++	++	++	-	+	-	+	++	++	++

Table 7.4: Requirements from function

storage of material. Nevertheless, it was deemed sensible to indicate the feasibility of storage costs by introducing this column.

Regarding the requirements from function (Table 7.4) it has to be annotated that the insulating capacity has been left out as it has been summarised in the previous chapter. Regarding Table 7.5 it should be pointed out that for the EPS granules due to the two distinct components (EPS granules + fillable plastic cover) two situations for the delivery time/availability and the origin/transport have to be distinguished. For the EPS granules themselves it shall be referred to the specifications made for EPS/XPS plates while the line for the EPS granules features the situation for the cover. The same applies for pallets with IR reflection: the transport/origin situation for the pallets and the additionally required wood is distinct from the one for the aluminium foil so that for the first it is referred to the line for pallets without IR reflection while the situation for the IR reflective aluminium foil is depicted in the line for pallets with IR reflection.

Floor Option	**Delivery time/Availability** Imm./ Stor.	Imm./ Avail.	Later	**Origin/Transport** Glo./ Plane	Glo./ Ship	Local	**Distribution** Lorry	Afoot
EPS/XPS plates		√				√		√
EPS granules (cover)	√		√	√				√
Pallets without IR reflect.		√				√	√	
Pallets with IR reflect. (alu. foil)		√		√			√	
Plastic floor tiles		√		√				√
Straw		√				√	√	
Cardboard		√				√		√
Bubble wrap		√				√		√
Acoustic floor mats		√				√		√

Table 7.5: Requirements from context (1)

	Cost			**Distribution**	**Assembly**			**Period of Use**	**Dismantling**	
Floor Option	material	transport	storage	number of packages	self-explanatory	entire floor	indeterminate material	6 month	ecological disposal	reusable
EPS/XPS plates	++	++		++	++	++	++	+	+	++
EPS granules	++	+		++	+	++	+	+	+	++
Pallets without IR reflect.	+	-		-	+	++	++	++	++	++
Pallets with IR reflect.	+	-		-	+	++	++	++	+	++
Plastic floor tiles	-	-		+	++	++	-	++	+	-
Straw	++	+		-	+	++	++	+	++	++
Cardboard	++	++		++	++	++	++	-	++	-
Bubble wrap	++	++		++	++	++	++	-	+	-
Acoustic floor mats	++	++		++	++	++	++	-	+	-

Table 7.6: Requirements from context (2)

Notes

[1]Saunders (2007), p. 43
[2]BASF AG (2007)
[3]Klaus (2007)
[4]Schwenk Dämmtechnik GmbH & Co. KG (2007)
[5]Rigips (2006)
[6]Klepper (2007)
[7]Rigips (2006)
[8]BASF AG, p. 5
[9]DIN V 4108-4 (1998-10), Paragraph 3.1, Table 1
[10]BASF AG (a), p. 5
[11]BASF AG, p. 5
[12]Sager AG (2006); Rigips (2004)
[13]Özkan (1983); Lyrer (2006)
[14]Gloor (2006)
[15]Konstant Online (2006)
[16]One spray can, as considered above, cost in 2007 6.80 € which sums up to 54.5 € for one floor.
[17]Buschkamp (2001); Sager AG (2006); Rigips (2004)
[18]BASF Plastics (2006)
[19]Korff & Co KG Isolierbaustoffe (2007)
[20]A partial exception to this is the above discussed Neopor/Lambdapor insulation, see Chapter 7.2.4.
[21]Künzel (2007)
[22]Calculation after DIN EN ISO 6946
[23]DIN EN ISO 6946 (1996-11)
[24]Conclusion of discussions during 4. Fachseminar: Wärmeschutz mit IR-reflektierenden Folien und Beschichtungen. Fraunhofer-Institut für Bauphysik, Stuttgart, Germany. 2007-03-27
[25]Corselli (2000), p. 43
[26]Feigl Paletten GmbH (2007)
[27]Feigl Paletten GmbH (2007); Lutz (2002), p. 245
[28]DIN EN ISO 6946 (1996-11)
[29]Mercateo AG (2007)
[30]DIN EN ISO 6946 (1996-11)
[31]Prima Direct, Vaughans of Leicester Ltd.
[32]Ferrino & C. S.p.A. p. 11
[33]Alber
[34]Food and Agriculture Organisation of the United Nations (FAO), Rome, Italy.
[35]Österreichisches Strohballen Netzwerk (2007)
[36]Deutsches Institut für Bautechnik (2006), p. 4
[37]Gammelin (2002), p. 33-34
[38]Österreichisches Strohballen Netzwerk (2007a)
[39]Deutsches Institut für Bautechnik (2006), p. 7
[40]Österreichisches Strohballen Netzwerk (2007b)
[41]TU Ilmenau, Fachbereich für Mathematik und Naturwissenschaften (2007)
[42]Ewifoam E. Wicklein KG (2007)
[43]Sealed Air Cooperation (2006)
[44]Verpackungsteam.com (2006)
[45]TU Ilmenau, Fachbereich für Mathematik und Naturwissenschaften (2007)
[46]Owens Corning (2006); Ewifoam E. Wicklein KG (2007a)

[47]Yatego GmbH (2007)

[48]Ewifoam E. Wicklein KG (2007a)

[49]It is assumed that the persons wear only underwear ($R = 0.09\ Clo = 0.014\ m^2K/W$) during sleeping, so that the thermal insulation by clothing can be neglected; see also Chapter 8.2.

[50]Exped (Expedition Equipement) AG (2006), p. 48

Chapter 8

Winterisation Kit for Emergency Shelters

8.1 Introduction

In order to provide a winterisation kit for emergency shelters, additional components beside the above discussed floor insulation are required. Therefore, widening the view for the design of an entire space habitable during winter, this chapter will start off dealing with the bedding and roof insulation as two integral components of a successful winterisation. Finally, the subjects for further research will be investigated which can be understood as an outlook and guidance for further development. To start with, an overview of additional winterisation features which should be part of the overall design of a winterised tent will be given. However, while all previous winterisation features could be either deployed for a winterisation kit (i.e. standard tent enhanced by winterisation kit) or a winterised tent (i.e. tent designed for winter deployment) these can presumably only be integrated in a winterised tent. Thereby, the question of the pros and cons of either option is raised which will be important to answer in order to proceed towards a fully winterised structure and will therefore be addressed subsequently. Finally, the chapter will be concluded by the summary of a testing programme for winterised tents.

8.2 Determination of Required Bedding Depending on Local Climate

8.2.1 Introduction

So far no method for the evaluation of the required bedding in order to gain thermal comfort for tent occupants sleeping on the ground exists. Therefore, methods applied to determine comfort temperatures for sleeping bags used for camping or polar expeditions have been exploited and adapted for the emergency relief context.

8.2.2 The TNO Model

The presented approach is based on a calculation method of the TNO Human Factors (Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek)[1], also known as TNO model, which has been in use for years. After practical tests with subjects and manikins (torso) the accuracy of the TNO model was improved by changing the proportion of the body directed downwards (25 %, before 40 %) and upwards (75 %, before 60 %)[2]. All subsequent calculations will be derived from this improved TNO model.

The TNO model determines the minimal comfort temperature, i.e. the minimal temperature for which the thermal comfort of a sleeping person is guaranteed, by first of all determining the total thermal resistance of a sleeping bag for 25 % of the body directed downwards and 75 % directed upwards as:

$$R_{ct} = \frac{1}{\frac{0.25}{R_{down}} + \frac{0.75}{R_{up}}} \tag{8.1}$$

with

$$R_{down} = \frac{d_{1500Pa}}{\lambda_{bed}} \tag{8.2}$$

$$R_{up} = \frac{d_{20Pa}}{\lambda_{bed}} + R_{air} \tag{8.3}$$

In order to account for the reduced thermal resistance due to the compression by the weight of the human body the material thickness (d_{1500Pa}) for R_{down} is determined under 1500 Pa pressure. For R_{up} the thermal resistance of an attached air layer ($R_{air} = 0.1\ m^2K/W$) is added to the thermal resistance of the sleeping bag with its thermal conductivity λ_{bed}. With this the minimal comfort temperature can be calculated as[3]:

$$T_{min} = T_{skin} - \frac{M \cdot R_{ct}}{A_{body}} \tag{8.4}$$

T_{skin}	skin temperature	$T_{skin} = 32\ °C$
M	metabolic rate	$M = 85\ W$
A_{body}	body surface area	$A_{body} = 1.8\ m^2$

It shall be annotated that the metabolic rate during sleeping can vary depending on the nutrition, gender, age etc. and hence, with potentially less heat produced by the body, more insulation becomes necessary[4]. Therefore, additional bedding should be made available for persons with a lower metabolic rate like children and elderly.

8.2.3 New Approach for Relief Items

Due to the comparatively low insulating capacity of relief items the above given method has to be changed from determining the minimal comfort temperature for a given bedding item to the determination of the required number of blankets and other insulation in order to provide thermal comfort for a given minimal temperature. Therefore, rather than calculating the total thermal resistance R_{ct} of a single item the following condition has to be satisfied for the totality of all insulating items provided:

$$Q = Q_{up} + Q_{down} \leq 85\ W \tag{8.5}$$

with

$$Q_{up} = \frac{1}{R_{cloth} + \frac{d_{20Pa}}{\lambda_{bed}} + R_{air}} \cdot 0.75 A_{body} \cdot (T_{skin} - T_i) \tag{8.6}$$

$$Q_{down} = \frac{1}{\frac{1}{2} \cdot R_{cloth} + \frac{d_{1500Pa}}{\lambda_{bed}} + \frac{d_i}{\lambda_i}} \cdot 0.25 A_{body} \cdot (T_{skin} - T_e) \tag{8.7}$$

T_i internal air temperature (in $°C$)
T_e external air temperature (in $°C$)

In Equation 8.6 and 8.7 the following adaptions with respect to the TNO model were undertaken: In the downwards heat flux (Q_{down}) the term d_i/λ_i was introduced to allow for i additional insulating layers beside the blankets. The second adaption became necessary as the TNO model applies for undressed persons which in general is not true in the disaster relief context. Therefore, the insulation by clothing (given in Clo) was added to the upwards and downwards thermal resistance. Due to the reduced thermal resistance of the clothing under compression of the body weight it is assumed that for the downwards heat flux the thermal resistance is reduced to half of its original value. The reasonableness of this assumption can be reinforced by the results for blankets under compression for which with the measured thickness under compression (d_{1962Pa}) the thermal resistance becomes about half of the uncompressed stage (see Table 8.1).

To prevent excessive cooling of one side of the body it should additionally be valid:

$$Q_{up} \approx Q_{down} \approx \frac{1}{2} Q \tag{8.8}$$

8.2.4 Thermal Properties of Relief Items

Prior to evaluating the required bedding it is necessary to determine the thermal properties of the relief items supplied. As the specifications of blankets have already been

blanket type	R_{up}	d_{1962Pa}	$\rightarrow$	R_{down}
medium th. resistance	0.20 m^2K/W	5 mm		0.12 m^2K/W
high th. resistance	0.30 m^2K/W	7 mm		0.17 m^2K/W

Table 8.1: Thermal properties of blankets

discussed in detail in Chapter 5.5.1, this paragraph will only summarise the relevant thermal properties in Table 8.1. The given thickness under a loading of 20 g/cm^2 i.e. 1 962 Pa is comparable to the compressed thicknesses used for the evaluation of camping sleeping bags. For the thermal conductivity of the compressed blankets the value used for the evaluation of sleeping bags after the TNO model i.e. $\lambda = 0.042\ W/mK$ is assumed, leading to the given values of R_{down} [5]. The appropriateness of this assumption is underlined by the thermal conductivity of wool or cotton felt, which with $\lambda = 0.04\ W/mK$ closely fit the before made assumption[6]. Determining the required number of blankets it is assumed that those blankets on which persons lay are folded once which means that they form a two-ply insulation towards the ground.

In extremely cold conditions mattresses or a floor insulation are considered in addition to blankets in order to avoid an excessive heat loss to the ground. For the mattresses it is assumed that the reduced thickness under the compressive loading of a person is 6 cm and that the thermal conductivity is $\lambda = 0.045\ W/mK$. For the floor insulation a thermal resistance of $R = 0.57\ m^2K/W$ is taken, which corresponds to the above presented floor option of a 2 cm layer of EPS (see Chapter 7.2.2). The downmost layer of the floor layout is formed by one or two layers of tarpaulin which function as a water barrier but have no significant influence on the thermal properties of the overall floor.

8.2.5 Tool for the Determination of Required Bedding

Using the above developed approach the required bedding was determined depending on the local climate for a temperature range (T_e) from 10 $°C$ to -20 $°C$ (see Figure 8.1 - 8.4). Due to the small differences between the air- and the ground temperature they are set to be equal. In correspondence with the distinction of an upwards heat loss (Q_{up}) and a downwards one (Q_{down}) the tables of Figure 8.1 - 8.4 distinguish in the line 'direction' between the required insulating items for a sufficient upwards insulation ($\uparrow$) or a downwards one ($\downarrow$). For both directions the required number of items is pointed out by the number of dots[7]. In order to account for varying local situations the calculations were carried out either for a heated or unheated tent and for fully dressed occupants or occupants wearing only underwear. Consequently four scenarios, each represented by one figure, are identified. Considering as an example the case A (Figure 8.1), for a minimum temperature of 0 $°C$ two medium and one high thermal resistance (th. res.) blankets are required for the upwards insulation and one high thermal resistance blanket is needed for the downwards insulation.

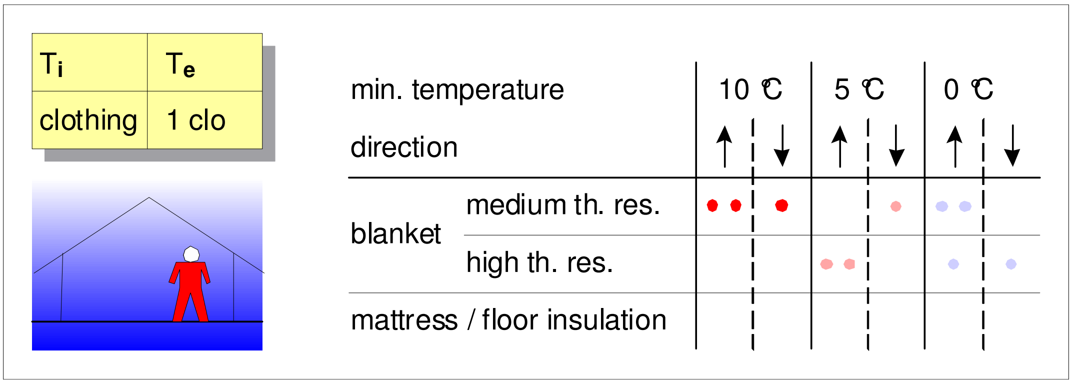


Figure 8.1: Required number of relief items for bedding (case A)

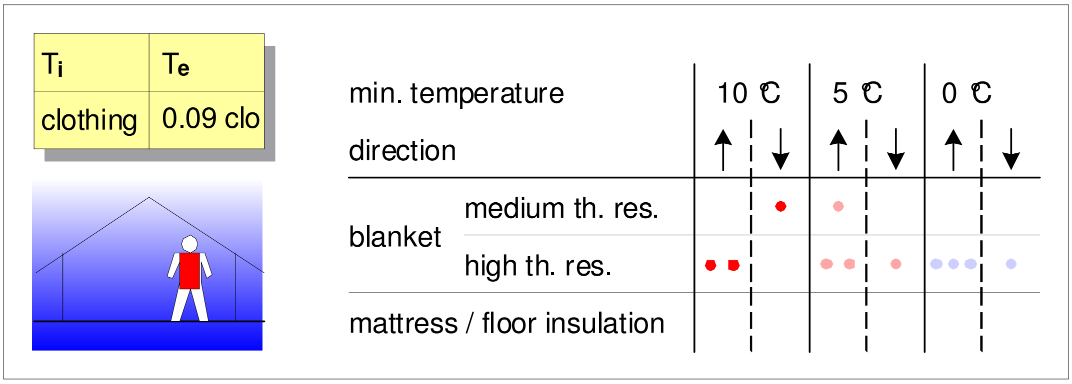


Figure 8.2: Required number of relief items for bedding (case B)

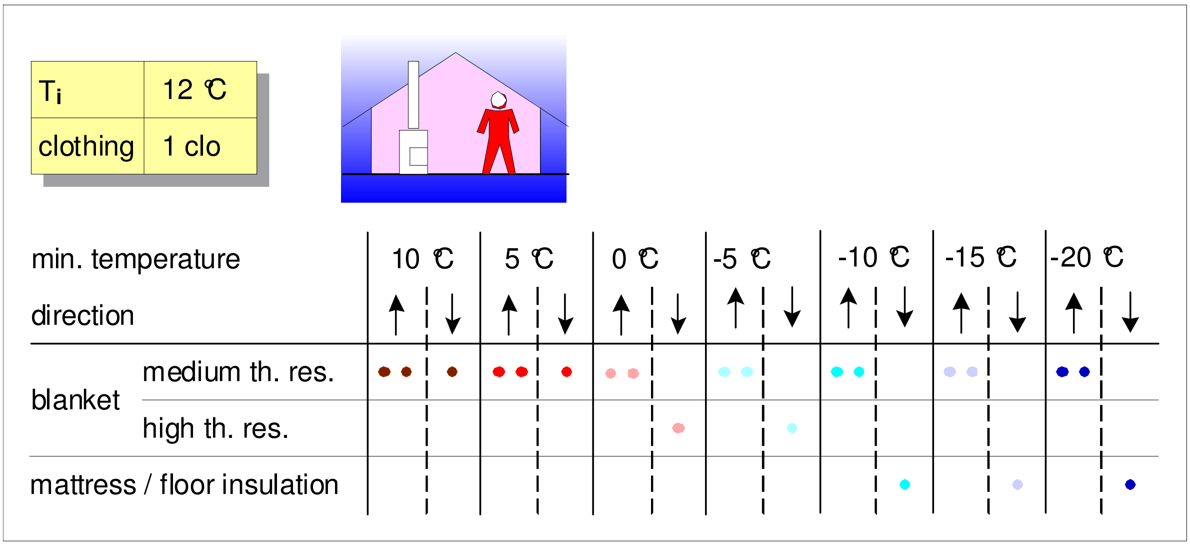


Figure 8.3: Required number of relief items for bedding (case C)

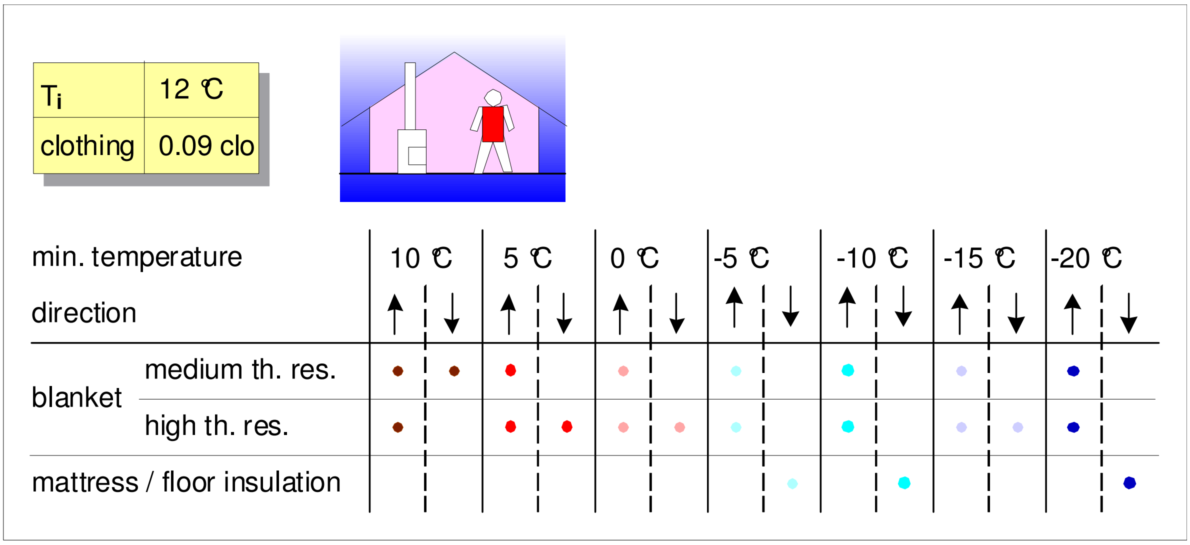


Figure 8.4: Required number of relief items for bedding (case D)

The primary distinction shall be made between the unheated (Figure 8.1 and 8.2) and the heated stage (Figure 8.3 and 8.4) as this difference results in the tabulation of a reduced temperature range for the unheated case. Setting for unheated tents $T_i = T_e$, the number of blankets required for an upwards insulation of the body increases significantly for a decreasing T_e. Consequently, for temperatures below -10 $°C$ three or more blankets are needed, so that it does not seem sensible to include temperatures below -10 $°C$. For the heated case an internal temperature of $T_i = 12$ $°C$ is assumed, as firstly the heating will be diminished during the night and as secondly the persons sleep on the ground and due to the poor insulation of tents a large stratification with low temperatures at ground level will occur. This constant internal air temperature signifies that, independent of tabulated external temperatures, the same number of blankets has to be provided to keep the invariable upwards heat flux sufficiently low (see Figure 8.3 and 8.4).

For the second computed parameter, the insulation by clothing, either a thermal resistance of 1 Clo for a fully dressed person (see also Chapter 5.6.1) or 0.09 Clo for a person in underwear (i.e. wearing panties and a sleeveless shirt) is considered[8]. Focusing on the upwards thermal insulation by clothing, the thermal resistance of 0.09 Clo, which corresponds to $R = 0.014$ m^2K/W, is nearly negligible, while 1 Clo (i.e. $R = 0.155$ m^2K/W) provides half the insulation of a high thermal resistance blanket (see Table 8.1). Consequently, comparing Figure 8.1 and 8.2 as well as Figure 8.3 and 8.4, it can be observed that the difference in clothing results in a constant difference in the required insulation by blankets. Regarding the downwards insulation such significant differences can not be found as in general the insulating capacity of the clothing which is halved by compression (see Equation 8.7) is of minor influence.

Focusing on the downwards insulation it can be noted that two-ply blankets provide sufficient insulation up to -5 or -10 $°C$. Only for lower temperatures either a mattress or a floor insulation is necessary. As, given the lack of data, these results are calculated with an assumed thermal conductivity of the blankets a verification by measuring the thermal conductivity of compressed blankets is recommended[9].

8.3 Roof Insulation

8.3.1 Design of Insulated Roof

Beside the insulation of the tent floor the thermal behaviour of the tent roof is of major importance as it represents the second surface which delimits the inhabited space from its surrounding. Therefore, the thermal behaviour of the three above listed, existing types of insulated tent roofs (see Chapter 5.3) have been investigated using the analytical method already deployed for the insulated tent floor. The thereby detected shortcomings have been overcome by developing three improved roof layouts. These have been designed as an improvement or addition to the LWET hoop tent with its 12 cm air layer between the inner and the outer shell (see also Chapter 5.2.2). Subsequently, all six layouts will be discussed. A comparison between them will illustrate the benefits which can be gained by incorporating IR reflective materials which has already been exploited successfully for the floor insulation. Given the existence of an insulating air layer in traditional roof layouts its thermal behaviour can easily be improved by using IR reflective material for the adjacent surfaces (see also Chapter 7.3.2 and 7.3.3). Furthermore, due to the good thermal performance and the low weight the usage of a number of layers of a standard multi-layered IR reflective insulation has been introduced (see also Chapter 7.2.8). Depending on the required thermal resistance, one or more layers of bubble wrap surrounded by IR reflective sheetings will form a new type of insulating layer, hereafter termed as IR refl. bubble wrap. A detailed description of the layout of all 6 regarded roofs is given in Table 8.2.

Analysing the thermal behaviour of the roofs, the heat loss through the roof (q) and the internal surface temperature (T_s) are critical as already highlighted for the floor insulation. Furthermore, the prevention of condensation on the inner surface of the roof is important, as it represents a frequent problem under winter conditions. Given the conditions within the tent, it can be assumed that condensation will occur at a temperature of about 13 $°C$ [10]. As the creation of a vapour barrier is not possible, it is important to investigate in which layer condensation will occur and if it can affect negatively the comfort of the tent occupants.

Subsequently, the three above named criteria shall be used to evaluate the different roof options. For this purpose it is assumed that the temperature within the tent is 20 $°C$ and outside the tent -20 $°C$. The thermal resistance of the IR reflective bubble

Type	Specification	Inner layer	Air layer	Outer insulation	Outer shell
Centre pole tent	desouti liner + outer fly	desouti liner	5 mm	–	cotton (+ outer fly)
Hoop tent 1	quilt insulation	quilt with felt filling	12 cm	–	polyester
Hoop tent 2	bubble wrap insulation	PP	–	6 mm IR refl. bubble wrap	PP
New design 1	quilt + IR refl. air layer	quilt with felt filling	12 cm, IR refl.	–	polyester
New design 2	IR refl. bubble wrap	polyester/ cotton	12 cm, IR refl.	4.2 mm IR refl. bubble wrap	polyester
New design 3	IR refl. bubble wrap + ventilation	polyester/ cotton	12 cm, IR refl. (ventilated)	10 mm IR refl. bubble wrap	polyester

Table 8.2: Layout of insulated tent roofs

wrap is determined using a thermal conductivity of $\lambda = 0.025\ W/mK$ as determined by hot-plate apparatus testing for the IR reflective, multilayer bubble wrap insulation Lupotherm B2+8 [11]. The thermal resistance of incorporated air layers is calculated as given in DIN EN ISO 6946 for unventilated air layers[12]. An exception to this is made for the new design 3: In order to remove condensed water from the air layer between the inner layer and the outer insulation, ventilation openings will be integrated, leading to a slight draught of an assumed air velocity of 0.5 m/s. To account for this the calculation procedure for unventilated air layers was modified by increasing the convective heat loss. For this purpose the same approach as given for the conductive heat losses within R_{se}, in which the coefficient for convection increases by the fourfold air velocity, was adopted[13]. The thermal resistance of layers with one IR reflective surface was calculated with a reduced emissity of $\epsilon_1 = 0.1$.

Table 8.3 summarises for all 6 roof layouts the results for the three previously defined criteria and the overall thermal resistance (R_T) which is a helpful value to allow for comparisons e.g. with the insulation of buildings. A distinction has to be made between the horizontal and the vertical, upwards heat flux through the roof as the thermal behaviour of air layers differs depending on the direction of the heat flux. Due to the upwards movement of warmed air, the thermal resistance of horizontal air layers is lower than the one of vertical ones. Hence, in Table 8.3 the heat flux q is always larger for the upwards, vertical direction than for the horizontal one apart from the centre pole tent. For this the heat loss through the roof is smaller than through the walls[14] as the roof features an additional layer represented by the fly sheet. As the fly sheet however

Type	Vertical heat flux				Horizontal heat flux			
	R_T	q	T_s	Condensation	R_T	q	T_s	Condensation
Centre pole tent	0.38 m^2K/W	106 W/m^2	9.4 $°C$	inner layer	0.35 m^2K/W	115 W/m^2	5.0 $°C$	inner layer
Hoop tent 1	0.46 m^2K/W	87 W/m^2	11.3 $°C$	inner layer	0.51 m^2K/W	79 W/m^2	9.8 $°C$	inner layer
Hoop tent 2	0.38 m^2K/W	105 W/m^2	9.5 $°C$	inner layer	0.41 m^2K/W	97 W/m^2	7.3 $°C$	inner layer
New design 1	0.71 m^2K/W	56 W/m^2	15.0 $°C$	inner layer	0.91 m^2K/W	44 W/m^2	14.3 $°C$	inner layer
New design 2	0.80 m^2K/W	50 W/m^2	15.0 $°C$	outer insulation	1.00 m^2K/W	40 W/m^2	14.8 $°C$	outer insulation
New design 3	0.85 m^2K/W	47 W/m^2	15.3 $°C$	outer insulation	0.92 m^2K/W	44 W/m^2	14.3 $°C$	outer insulation

Table 8.3: Thermal properties of insulated tent roofs

does not form a sealed air layer with the rest of the tent but is spanned 25 cm above the outer shell it has thermally to be treated as a well ventilated air layer. After DIN EN ISO 6946 it has to be accounted for this type of air layer by the thermal resistance R_{se} determined for a wind velocity of 0 m/s [15].

Analysing the results obtained for the three existing tent types it can be seen, that the heat loss q is extremely high for the centre pole tent and the hoop tent 2, while the quilt used as an insulating layer for the hoop tent 1 design leads to a reduction in the heat loss. Another shortcoming is the very low temperature of the inner surface which generates thermal discomfort for two reasons: firstly because of the low radiation temperature and secondly due to the condensation on the inside of the inner tent. Comparing the design of hoop tent 1 with the new design 1, which differ only in the characteristic of the insulating air layer, it can be seen how the thermal properties can be significantly improved by coating the inside of the outer tent with IR reflective material. A reduction in the heat loss of 37 % is obtained while the surface temperature can be raised by more than 3 $°C$. However, the problem of condensation remains, as the temperature drops below 13 $°C$ within the inner layer. In order to overcome this problem a large temperature decrease in the inner layer has to be avoided, which consequently shifts the condensation to an outer layer where it is less harmful as not in immediate contact with the living area of the tent occupants. Therefore, the insulating layer has to be removed from the inner fold to the outer fold which is exhibited in the new design 2: Instead of deploying an inner tent insulated by felt, the outer shell is insulated by 4.2 mm thick bubble wrap covered on both sides with IR reflective sheeting. Beside the additional reduction in the heat loss and the increase in the surface temperature, this design distinguishes as the temperature drop below 13 $°C$ occurs in the air layer causing condensation on the inner surface of the outer tent. The final optimisation towards the new design 3 is the introduction of ventilation openings in order to allow for the removal of the condensed water. Given the thereby introduced slight draught in the insulating air layer and the consequently reduced thermal resistance of it, it was necessary to increase the thickness of the bubble wrap layer to 1 cm in order to reach a performance similar to the one of the new design 2. Comparing the results of new design 2 and 3 with the ones of hoop tent 2, which deployes as well IR reflective bubble wrap, significant differences can be observed although the thickness of the bubble wrap layer for the existing design lays between those of the new design 2 and 3. The poorer performance of hoop tent 2 is the result of covering the IR reflective outer surfaces of the bubble wrap layer by PP sheeting which prevents an improved thermal behaviour of the adjacent air layer. Therefore, it has to be concluded, that the existing design does by far not exploit the large capacity of the used materials. Concluding, it shall be noted that due to the restricted time and resources all results have been obtained analytically and that further practical testing is required (see also Chapter 8.4.4).

To graphically summarise the obtained results, Figure 8.5 compares the temperature gradients of hoop tent 1 and new design 3 clearly indicating the achievements in form of a raised surface temperature and a removal of the condensation from the inner surface. Comparing the overall heat loss through the tent roof, a reduction of 45 % from 3 330 W to 1 838 W could be gained. Regarding the progress from new design 1 towards new design 3 it can be seen that finally a well performing roof layout was developed which satisfies all previously defined thermal criteria. Given the fact that the significant improvements were gained by simply adding a 1 cm thick layer of IR reflective bubble wrap to the outer shell of a standard LWET tent, the found solution represents an easy to deploy, light, low cost and thermically highly efficient addition that could become part of a winterisation kit.

8.3.2 Deployment of IR Reflective Materials for External Roof Surface

Beside the previously exploited benefit of IR reflective materials inside the insulating layers of the tent roof, a use on the outer shell shall be investigated. This investigation can best be motivated by giving a well known example from nature. After cold, calm nights with a clear sky it can be observed that white frost has formed on grass although the air temperature did not drop below 0 $°C$. With no radiative gains from sun light and a reduced counter-radiation as a consequence of the lacking cloud cover, a large amount of heat is radiated from the surface of the grass to the much cooler atmosphere. Given a temperature of the atmosphere of about $T_\infty = 10\ K$ and the inclusion of temperature in the equation for radiative heat losses by the power of 4 (see Stefan-Boltzmann law, i.e. q_r

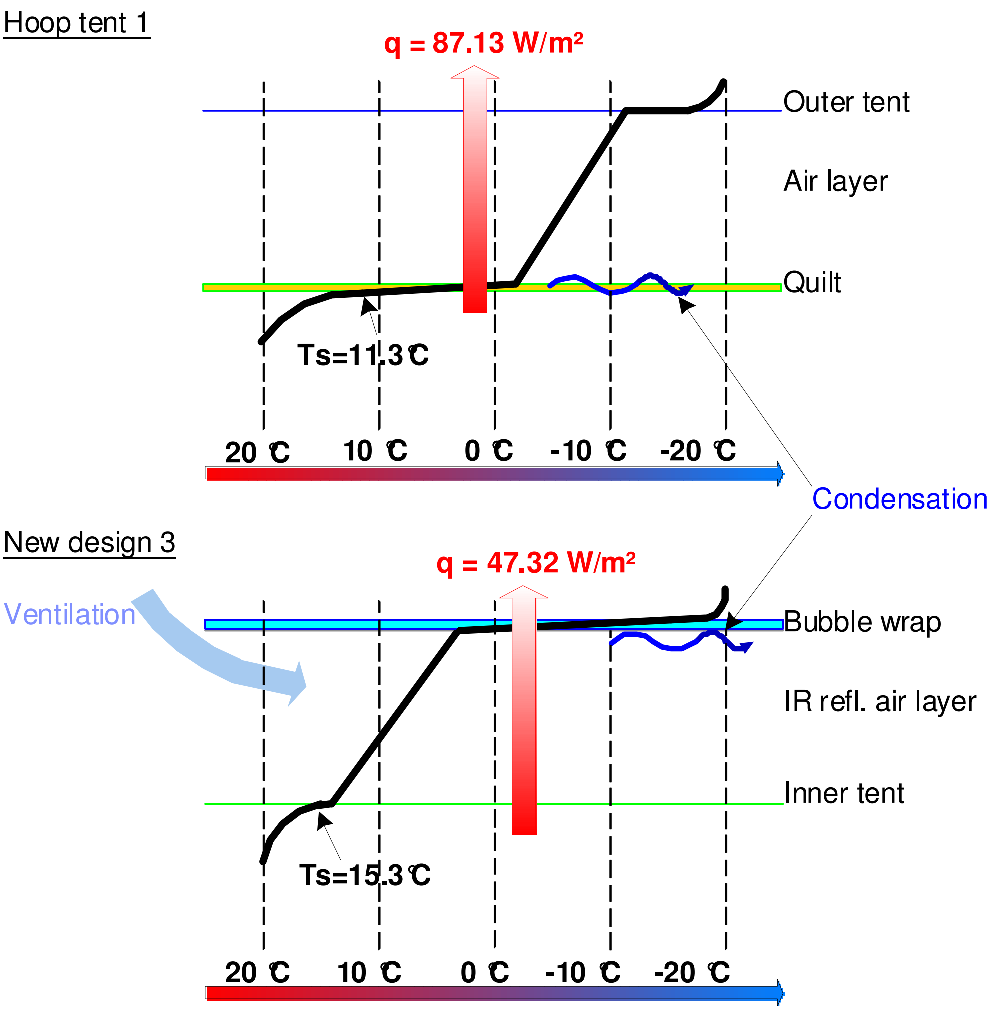


Figure 8.5: Temperature gradient in insulated tent roofs

below), with the present temperature difference the massive heat loss is evident. As the heat loss can not be compensated by heat gained from convection of the warmer air and conduction from vegetation and earth underneath, the surface temperature of the grass drops significantly. Hence, radiative losses during clear nights can significantly reduce the surface temperature[16]. Therefore, it seems sensible to investigate to which degree low emissivity surfaces with their consequently reduced radiative losses could prevent an excessive reduction of the surface temperature and contribute to improve the overall thermal behaviour of tent roofs.

So far the heat lost by radiation and convection at the outer surface of the roof has been summarised after DIN EN ISO 6946 by the coefficient R_{se} (see also Chapter 6.3.2). As this value accounts for an average situation and is based on the deployment of

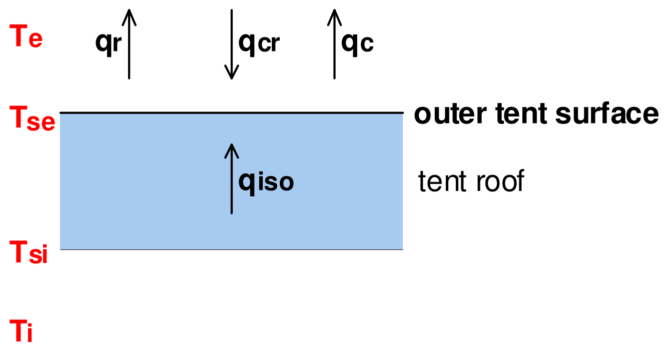


Figure 8.6: Thermal equilibrium at outer tent surface

materials with $\epsilon = 0.9$, it can not be used for the here regarded, different situation. Therefore, it is necessary to formulate the thermal equilibrium for the outer tent surface for all occurring heat fluxes q as depicted in Figure 8.6. The heat flux q_r represents the radiative losses to the sky and can be expressed by the Stefan-Boltzmann law. q_{cr} is the counter-radiation which is dependent on the cloud cover. As the worst case shall be assumed, the lowest possible thermal gains by counter-radiation are considered using an equation for a cloudless sky based on the Angström formula[17]. The convective heat loss q_c is based on the coefficient for heat loss by convection h_c as given in DIN EN ISO 6946 [18]. Finally, q_{iso} represents the conductive heat loss throughout the insulated roof with i layers. Consequently, the thermal equilibrium can be formulated as follows:

$$0 = -q_r + q_{cr} - q_c + q_{iso} \tag{8.9}$$

$$\Leftrightarrow 0 = -\epsilon \cdot \sigma \cdot \left(T_{se}^4 - T_{\infty}^4\right) + \epsilon \cdot \sigma \cdot a_{cr} \cdot T_e^4 - h_c \cdot (T_{se} - T_e) + \frac{1}{R_{si} + \sum R_i} \cdot (T_i - T_{se}) \tag{8.10}$$

$$with \qquad a_{cr} = 0.790 - 0.174 \cdot 10^{-0.041 \cdot e}$$

$$and \qquad h_c = 4 + 4 \cdot \nu$$

ϵ	emissity (in -)
σ	Stefan-Boltzmann constant ($\sigma = 5.6698 \cdot 10^{-8}\ W/(m^2 \cdot K^4)$)
T	temperature (in K)
e	vapour pressure (in hPa, here assumed $e = 6\ hPa$)
ν	wind velocity (in m/s)

T_e = -20°C v = 4,0 m/s ε = 0,9					
T_se	q_r	q_cr	q_c	q_iso	Σ
-19,71	-210,05	144,68	-5,86	49,31	-21,91
-19,81	-209,72	144,68	-3,86	49,43	-19,46
-19,91	-209,38	144,68	-1,86	49,56	-17,00
-20,01	-209,05	144,68	0,14	49,68	-14,55
-20,11	-208,72	144,68	2,14	49,80	-12,09
-20,21	-208,39	144,68	4,14	49,93	-9,64
-20,31	-208,06	144,68	6,14	50,05	-7,19
-20,41	-207,73	144,68	8,14	50,18	-4,73
-20,51	-207,41	144,68	10,14	50,30	-2,28
-20,61	-207,08	144,68	12,14	50,43	0,17
-20,71	-206,75	144,68	14,14	50,55	2,63
-20,81	-206,42	144,68	16,14	50,67	5,08

Figure 8.7: Solution of thermal equilibrium equation for varying T_{se} ($\epsilon = 0.9$)

		$\nu = 4.0\ m/s$		$\nu = 1.5\ m/s$	
	ϵ	T_{se}	q_{iso}	T_{se}	q_{iso}
without IR refl. (DIN)	0.9	-18.1 $°C$	47.32 W/m^2	-16.8 $°C$	45.70 W/m^2
without IR refl.	0.9	-20.6 $°C$	50.43 W/m^2	-21.0 $°C$	50.91 W/m^2
with IR refl.	0.1	-18.0 $°C$	47.20 W/m^2	-16.3 $°C$	45.08 W/m^2
IMPROVEMENT		+2.6 $°C$	-3.23 W/m^2	+4.7 $°C$	-5.83 W/m^2

Table 8.4: Thermal performance of IR reflective outer shell ($T_e = -20\ °C$)

Given the nature of Equation 8.10 an iterative solution became necessary, which was carried through for a varying surface temperature T_{se} (see Figure 8.7). As the new design 3 was identified as the best performing roof insulation (see Chapter 8.3.1), it was tested if it could be further improved by an outer IR reflective surface. The initial performance of this design as determined after DIN EN ISO 6946 was $q_{iso} = 47.32\ W/m^2$ and $T_{se} = -18.1\ °C$. As before for the various roof layouts the thermal behaviour was tested for $T_i = 20\ °C$ and $T_e = -20\ °C$. Due to the large influence of the wind velocity via h_c on the convective heat losses and consequently the overall result two cases have been analysed: firstly a wind velocity of 4 m/s as given as the standard wind velocity in DIN EN ISO 6946 and secondly calmer conditions with $\nu = 1.5$ m/s. It shall be annotated that in the case of $T_{se} < T_e$, which is true in a number of cases, the sign of q_c changes representing the thermal gains from the warmer surrounding air.

The results for the original new design 3 without an IR reflective surface and for the improved layout with an IR reflective outer shell are summarised in Table 8.4. Comparing the results without an IR reflective outer shell as calculated after DIN EN

T_e = -20°C v = 4,0 m/s ε = 0,1					
T_se	q_r	q_cr	q_c	q_iso	Σ
-17,11	-24,31	16,08	-57,86	46,08	-20,01
-17,21	-24,27	16,08	-55,86	46,20	-17,85
-17,31	-24,24	16,08	-53,86	46,33	-15,69
-17,41	-24,20	16,08	-51,86	46,45	-13,53
-17,51	-24,16	16,08	-49,86	46,58	-11,37
-17,61	-24,12	16,08	-47,86	46,70	-9,20
-17,71	-24,08	16,08	-45,86	46,82	-7,04
-17,81	-24,05	16,08	-43,86	46,95	-4,88
-17,91	-24,01	16,08	-41,86	47,07	-2,72
-18,01	-23,97	16,08	-39,86	47,20	-0,56
-18,11	-23,93	16,08	-37,86	47,32	1,61
-18,21	-23,90	16,08	-35,86	47,44	3,77

Figure 8.8: Solution of thermal equilibrium equation for varying T_{se} ($\epsilon = 0.1$)

ISO 6946 with those calculated after the thermal equilibrium, it can be observed, that the heat loss q_{iso} for the thermal equilibrium is in fact larger than the one previously calculated after the DIN. This can be explained by the fact that the values for R_{se} in the DIN reflect average conditions and consequently do not represent the highest possible heat loss which occurs in the here regarded scenario. It implies that the heat losses throughout the different roof layouts as calculated in the previous chapter will certainly be exceeded during clear nights. Drawing the attention upon a comparison of the values obtained for the different surface characteristics, it can be seen that the IR reflective material leads to an decrease in the heat loss q_{iso} while the surface temperature (T_{se}) is raised. However, the degree to which improvements can be gained, largely depends on the wind conditions. For $\epsilon = 0.9$ the radiative heat loss ($q_r - q_{cr}$) exceeds the heat gains from q_{iso} so that thermal gains by convection for $T_{se} < T_e$ are necessary (see Figure 8.7). These gains are larger for a higher wind velocity so that the surface temperature does not drop as much as for calm conditions and consequently the required q_{iso} is lower. In contrast to this, the situation for $\epsilon = 0.1$ is different as the obtained reduction of q_r is so significant that the thermal gains from q_{iso} exceed the radiative losses (see Figure 8.8). Therefore, thermal equilibrium is achieved as soon as the convective losses compensate the excess heat from q_{iso}. Under windy conditions this is evidently true for a lower surface temperature and consequently for a higher q_{iso} than for calm conditions. Concluding, the considered improvement reduces the heat loss by 6.4 % for $\nu = 4\ m/s$ and by 11.5 % for $\nu = 1.5\ m/s$.

As for the evaluation of the benefits of an IR reflective outer shell not only its performance under extremely low temperatures (i.e. $T_e = -20\ °C$) but as well over the entire service period is of interest, additionally the situation for a higher external tem-

	ϵ	$\nu = 4.0\ m/s$ T_{se}	q_{iso}	$\nu = 1.5\ m/s$ T_{se}	q_{iso}
without IR refl. (DIN)	0.9	0.95 °C	23.66 W/m^2	1.6 °C	22.85 W/m^2
without IR refl.	0.9	-2.45 °C	27.88 W/m^2	-4.1 °C	29.93 W/m^2
with IR refl.	0.1	0.75 °C	23.91 W/m^2	1.3 °C	23.22 W/m^2
IMPROVEMENT		+3.2 °C	-3.97 W/m^2	+5.4 °C	-6.71 W/m^2

Table 8.5: Thermal performance of IR reflective outer shell ($T_e = 0\ °C$)

T_e = 0°C	v = 4,0 m/s	ε = 0,9			
T_se	q_r	q_cr	q_c	q_iso	Σ
-1,55	-277,05	196,15	31,07	26,76	-23,07
-1,65	-276,64	196,15	33,07	26,89	-20,54
-1,75	-276,24	196,15	35,07	27,01	-18,00
-1,85	-275,83	196,15	37,07	27,14	-15,47
-1,95	-275,42	196,15	39,07	27,26	-12,94
-2,05	-275,02	196,15	41,07	27,39	-10,41
-2,15	-274,61	196,15	43,07	27,51	-7,88
-2,25	-274,21	196,15	45,07	27,63	-5,35
-2,35	-273,80	196,15	47,07	27,76	-2,82
-2,45	-273,40	196,15	49,07	27,88	-0,29
-2,55	-272,99	196,15	51,07	28,01	2,23
-2,65	-272,59	196,15	53,07	28,13	4,76

Figure 8.9: Solution of thermal equilibrium equation for varying T_{se} with $T_e = 0\ °C$ ($\epsilon = 0.9$)

perature ($T_e = 0\ °C$) was analysed (see Table 8.5). For $\epsilon = 0.9$ this results in a reduced q_{iso} and increased radiative losses which creates a much higher thermal imbalance than observed for $T_e = -20\ °C$ (see Figure 8.9). Hence, taking the values after DIN as point of reference thermal equilibrium can only be obtained for a larger reduction in T_{se} and consequently a larger increase in q_{iso} as compared to the previously analysed situation. Under this conditions the reduction of ϵ to 0.1 leads to a more significant change in the thermal equilibrium situation so that the overall benefits by the IR reflective material increase to 14.2 % for $\nu = 4\ m/s$ and to 22.4 % for $\nu = 1.5\ m/s$.

Although the thermal potential of an IR reflective outer shell has been demonstrated, a final evaluation seems only possible researching the below listed remaining questions:

Will a silvery glittering tent be accepted by the occupants?

How will the weathering influence the emissivity of the IR reflective material? (Due to the novelty of the material so far no results are available.)

Which wind velocity and further influences introduced by the movement of the outer shell in the wind will have to be considered for the determination of the convective losses?

How has the reduction of solar gains during the day to be evaluated with respect to the overall thermal performance of the tent?

8.4 Subjects for Further Research

8.4.1 Introduction

In addition to the previously presented features of a winterisation kit, which have been researched in detail, the subsequent part of this chapter will deal with the remaining open points, which still need consideration in order to proceed towards a fully winterised tent. Therefore, the following can be understood as a guidance for further research.

8.4.2 Additional Winterisation Features

Beside the previously discussed insulation of the floor and the roof a number of other features are of importance for the winterisation of tents as listed below:

Snow clearance: In order to prevent an overloading of the structure and a subsequent tent collapse due to snow its clearance should be facilitated by the design. The use of a ridge type roof rather than a hoop type one and the deployment of a slippery material for the outer shell are helpful features.

Structural stability: Given the potential loading with snow winterised tents should be designed for a higher loading than standard tents. Due to their superior structural stability the deployment of geodesic domes as used for all-season camping and polar tents seems advisable (see Chapter 5.6.2). As this however contradicts the recommended shape for snow clearance a detailed investigation of the benefits and shortcomings of both designs will be necessary in order to decide upon the best solution.

Removal of condensation: Beside the avoidance of condensation on the inner surface of the tent, which should be addressed by the design of the roof layout (see Chapter 8.3.1), the removal of condensation should be facilitated by the integration of vents (see Chapter 5.6.3).

Fire protection: Given the use of stoves in winterised tents and the resulting danger of tent fires the use of fire-retardant materials would be a sensible measure of fire protection.

8.4.3 Winterisation Kit versus Winterised Tent

As mentioned above generally two options for the winterisation of tents exist: either the provision of a winterisation kit which is provided in order to improve the performance of a standard tent, or the deployment of winterised tents which are developed explicitly for the cold climate context. Proceeding towards a fully winterised tent, a decision for either option will become necessary. Therefore subsequently, consideration will be given to the advantages and disadvantages of both solutions.

The following components should be included in a ***winterisation kit:***

Floor insulation

Additional roof layer

Appropriate bedding

Stove and flue pipe

Information leaflet

The leaflet should provide the necessary information on how to construct the insulated floor and roof as well as on how to operate the tent during winter conditions. This includes precautions against tent fires and the clearance of snow from roofs.

However, the approach chosen by the UNHCR aims for the development and supply of ***winterised tents***. One major advantage of winterised tents is that they can accommodate the additional winterisation features as discussed in the previous subchapter to a much higher degree than a winterisation kit. To get an overview of the key advantages and disadvantages of both options it shall be referred to Figure 8.10. Opting for the deployment of winterised tents signifies that two standard tents (one for summer, one for winter) would exist and consequently would have to be stored. As compared to the supply and storage of winterisation kits, this would imply a higher investment in stored supplies and the need for larger storage capacities. With respect to the immediate transport volume it shall be annotated that, given the restricted transport capacities after disasters, it can be crucial to supply as many affected as possible with a very basic, small volume shelter and improve this at a later stage rather than supplying only a portion of the affected with an appropriate shelter. It shall be underlined that the given comparison does not provide any weighting factors. These will be subject to the individual preferences of the aid agencies which will take the final decision to adopt one of the two options.

8.4.4 Testing Programme for Winterised Tents

Evaluating the thermal properties which resulted from a UNHCR test on 16 prototypes of winterised tents in March 2007, it is apparent that not only the development of the

	Winterisation kit	Winterised tent
Number of standard tents	1	2 (summer + winter)
Entirely designed for winter use	no	yes, e.g. stronger frame
Storage capacity	only winterisation kits	entire winterised tents
Investment in stored supplies	only winterisation kits	entire winterised tents
Immediate transport volume	later on delivery of wint. kits	entire winterised tents
Delivery effort	duplicated	once
Use during summer period	removal of winterisation kit	?

Advantages   Disadvantages

Figure 8.10: Winterisation kit versus winterised tent

tents themselves, but as well of appropriate testing methods is crucial for the process towards fully winterised tents[19]. Only with appropriate testing methods it will be possible to compare different solutions and improve them further until the required properties are gained. Therefore, subsequently a testing programme for winterised tents is proposed, split in an analytical and a practical part.

Analytical Testing

Beside the previously presented analysis of the thermal behaviour of the roof and floor insulation it seems necessary to investigate analytically the structural stability of both canvas and frame under snow and wind loading.

Practical Testing

The practical testing should be carried through in a laboratory and in the field.

A) Laboratory Testing

In order to obtain detailed information on the overall thermal behaviour of the tents, testing in a climatic chamber is required. In addition to the analytical investigation of the thermal properties this testing can provide information on complex thermodynamical processes like the fluid-solid interaction between the air inside the tent moved by heating and the solid tent shell. For the testing the following boundary conditions have to be provided:

- sufficiently low temperature of both air and floor
- variable wind velocity

– appropriate heat source

A weak point observed in previous tests is the selected type of heat source. To avoid errors introduced by the heat source a stove as deployed in the field or at least a heat source with a similar heat output and way of transmission should be selected. The test measurements can be carried out either for a given heater output investigating the resulting air temperature or for a fixed air temperature measuring the required heat input. Independent of the selected approach the following data should be collected:

– internal air temperature / heat input (also for different wind velocities)
– stratification of the internal air temperature
– thermal images

Thermal images can provide valuable information on thermal bridges and local weaknesses of a design.

B) Field Testing

Having obtained positive results in the analytical and thermal chamber testing, field testing becomes necessary before finally considering a tent for large scale deployment. For the field testing the following criteria are of major importance:

– ease of construction
– structural stability
– thermal comfort
– occurrence of condensation
– living quality
– durability

Finally, the result should be a fully winterised tent which provides comfort to homeless in cold climate disaster regions.

Notes

[1]Netherlands Organisation for Applied Scientific Research

[2]Den Hartog (2001)

[3]Den Hartog (2001), p. 1

[4]Mammut Sports Group AG (2003), pp. 3-5

[5]Den Hartog (2001), p. 1

[6]Nierobis (2003)

[7]The different colour of the dots was chosen to identify a set of upwards and downwards insulation for a given temperature.

[8]Innova AirTech Instruments A/S, pp. 27-28

[9]A correspondence with Intertek Labtest UK Limited, which certificates the thermal resistance of relief blankets, proved, that so far thermal properties under compression are not tested (Maplesden).

[10]Hammerschmidt (2006)

[11]Planungsgruppe Dach (2005)

[12]DIN EN ISO 6946 (1996-11)

[13]DIN EN ISO 6946 (1996-11)

[14]Even though it was defined that the entire upper structure of the tent shall be termed roof, here an exception has to be made: the distinction of vertical walls and on top of them a roof becomes necessary due to their different layouts.

[15]DIN EN ISO 6946 (1996-11)

[16]Grigull (1979), p. 70

[17]Wikipedia (2007)

[18]DIN EN ISO 6946 (1996-11)

[19]Vallée (2007)

Chapter 9

Conclusion

Having already widened the view from the very specific design of a floor insulation to the overall winterisation of tents, this last chapter will further open the perspective upon a summary of all major results obtained in this work. This will be dealt with in correspondence to the sequence of the chapters.

Starting off with a very general investigation of post-disaster homelessness it was first of all possible to develop a pre- and post-disaster risk management process for disaster induced homelessness. Beside the numerous other contributing factors, it identified the significant role of preparedness in the sense of an availability of adequate emergency shelters. Subsequently, the undertaken risk analysis of post-disaster homelessness showed a large variation in the occurrence of homelessness over different disaster types and regions. Focusing on the number of homeless provoked by earthquakes, beside the significance of the Richter scale magnitude, the large influence of the human development status represented by the HDI was proved. As a final result a risk index for homelessness due to earthquakes was developed, identifying countries of an endangerment risk class 4 and medium human development ($0.5 \leq \mathrm{HDI} < 0.8$) as the ones at highest risk.

Widening the view from the generation of homelessness upon the post-disaster sheltering situation, the large influence of structural and human vulnerability on both could be demonstrated. As structural and human vulnerability depend on the socio-economic boundary conditions, these represent a key factor in not only reducing the generation of homelessness but as well in improving the post-disaster shelter situation. Furthermore, the influence of the socio-economic boundary conditions and the human vulnerability does not only explain the specific characteristics of the post-disaster shelter situation with different types of emergency shelters used and a varying duration of the reconstruction phase, but highlights as well, that adequate shelter help can only be given within the corresponding socio-economic context.

Regarding the winterisation of emergency shelters a large demand for improved winterised tents could be identified. This judgment was derived from both, analysing the degree of tent winterisation after disasters in cold climate regions, as well as from researching the availability of appropriate winterised tents. Investigating the design of cold climate tents used in other contexts such as polar expeditions, it has to be concluded that the possibilities of a knowledge transfer are very limited given the very specific requirements for emergency shelters.

With respect to the necessary winterisation features the floor insulation is especially crucial, as it is an integral component for thermal comfort inside the tent and difficult to provide with restricted resources. So far the deployed tents do not provide any floor insulation other than one or two layers of plastic sheeting, and the subject has been widely neglected in past attempts to improve winterised tents. This results not only in the absence of available solutions but as well in the fact that neither requirements nor evaluation methods for a floor insulation have been formulated. Given the fundamental function of both, requirements and evaluation methods as a starting point for any development, they have been derived from past disaster experiences, comments of experts and building codes. Based on them, it was possible to design a number of floor insulations which not only provide good thermal properties but as well conform with the context e.g. low cost, ease of transport and construction. Even though the requirements for building materials are very similar to those for a floor insulation, it was found that only two products (EPS/XPS plates and EPS granules) are suitable for the different context. With the identification of straw, timber forklifts and IR reflective plastic floor tiles as beneficial solutions, it was demonstrated that options from a large number of fields ranging from traditional insulating materials to innovative products can be used. Especially promising seems the use of IR reflective materials which have recently been introduced in the building industry as an insulation material. Due to their excellent thermal properties in combination with a low volume, weight and price they suit the given requirements very well, and the benefits of their usage for the floor insulation, as well as for the roof insulation have been highlighted. Furthermore, it was found that thin layer solutions such as cardboard cannot provide thermal comfort but represent a good transitional solution.

As additional components of a winterisation kit, the bedding and the roof insulation were researched in detail. Observing the situation for bedding, a clear problem is the absence of any guidance on the required bedding items which constitute an integral element in the creation of thermal comfort during sleeping. Exploiting the well researched methods for the evaluation of camping sleeping bags and adopting them for the given context, it became possible to provide a calculation method which allows to determine the required number of bedding items of a certain quality, depending on the local climate and the dress code, as well as on the optional heating and floor insulation. The final result is an easy to deploy tool that allows relief workers in the field to determine in correspondence with the local situation, which items have to delivered in order to provide thermal comfort during sleeping. Analysing the thermal properties of winterised tent roofs and identifying their shortcomings, it was possible to propose an improved insulated roof layout. As key features a reduction of the heat loss throughout the roof, an increase in the internal surface temperature and the removal of condensation from the inner tent surface were achieved using a 10 mm thick IR reflective bubble wrap insulation of the outer tent. This insulation is not only characterised by a low volume, weight and cost but could easily be used as a winterisation component allowing to adapt standard tents for cold climate conditions. A promising starting point for further improvements is the deployment of an IR reflective outer tent surface which would have a positive effect on the insulating capacity when heat losses are highest, i.e. during clear nights.

Given the proposed floor and roof insulation in combination with the guidance on bedding, the present work has covered many important aspects of a winterisation kit for emergency shelters. It is hoped that they will soon contribute to finalising a fully winterised tent which offers an appropriate and warm emergency shelter to those which are most in need as in the aftermath of a natural disaster in a cold climate region a tent remains their only option for shelter. Regarding the overall risk management process, fully winterised tents would not only increase the preparedness for natural disasters but with people staying in appropriate shelters extend the time available for reconstruction. This would provide the valuable chance for a better reconstruction and the integration of risk reduction measure so that winterised tents could finally contribute to improve the overall shelter situation.

Appendix A

Analysis of Homelessness

A.1 Allocation of Countries in Regions

AFRICA	AMERICA	ASIA	EUROPE/OCEANIA
Central Africa	**Caribbean**	**East Asia**	**European Union**
Angola	Anguilla	China P Rep	Austria
Cameroon	Antigua and Barbuda	Hong Kong (China)	Belgium
Central African Rep	Bahamas	Japan	Cyprus
Chad	Barbados	Korea Dem P Rep	Czechoslovakia
Congo	Cayman Islands	Korea Rep	Denmark
Gabon	Cuba	Macau	Finland
Zaire/Congo Dem Rep	Dominica	Mongolia	France
	Dominican Rep		Germany
East Africa	Grenada	**South Asia**	Greece
Burundi	Guadeloupe	Afghanistan	Hungary
Comoros	Haiti	Bangladesh	Ireland
Djibouti	Jamaica	Bhutan	Italy
Eritrea	Martinique	India	Luxembourg
Ethiopia	Montserrat	Iran Islam Rep	Netherlands
Kenya	Netherlands Antilles	Maldives	Poland
Madagascar	Puerto Rico	Nepal	Portugal
Malawi	St Kitts and Nevis	Pakistan	Spain
Mauritius	St Lucia	Sri Lanka	Sweden
Mozambique	St Vincent/Grenadines		United Kingdom
Reunion	Trinidad and Tobago	**South-east Asia**	
Rwanda	Turks and Caicos Is	Cambodia	**Rest of Europe**
Seychelles	Virgin Is (UK)	East Timor	Albania
Somalia	Virgin Is (US)	Indonesia	Bulgaria
Tanzania Uni Rep		Lao P Dem Rep	Iceland
Uganda	**Central America**	Malaysia	Norway

AFRICA	**AMERICA**	**ASIA**	**EUROPE/OCEANIA**
Zambia	Belize	Myanmar	Romania
Zimbabwe	Costa Rica	Philippines	Switzerland
	El Salvador	Thailand	Turkey
North Africa	Guatemala	Vietnam	Yugoslavia
Algeria	Honduras		
Egypt	Mexico	**West Asia**	**Former Soviet Union**
Libyan Arab Jamah	Nicaragua	Iraq	Soviet Union
Morocco	Panama	Israel	
Sudan		Jordan	**Oceania**
Tunisia	**North America**	Kuwait	American Samoa
	Bermuda	Lebanon	Australia
Southern Africa	Canada	Oman	Cook Is
Botswana	United States	Saudi Arabia	Fiji
Lesotho		Syrian Arab Rep	French Polynesia
Namibia	**South America**	Yemen	Guam
South Africa	Argentina		Marshall Is
Swaziland	Bolivia		Micronesia Fed States
	Brazil		New Caledonia
Benin	Chile		New Zealand
Burkina Faso	Colombia		Niue
Cape Verde Is	Ecuador		Papua New Guinea
Cote d'Ivoire	French Guiana		Samoa
Gambia The	Guyana		Solomon Is
Ghana	Paraguay		Tokelau
Guinea	Peru		Tonga
Guinea Bissau	Uruguay		Tuvalu
Liberia	Venezuela		Vanuatu
Mali			Wallis and Futuna Is
Mauritania			
Niger			
Nigeria			
Senegal			
Sierra Leone			
St Helena			
Togo			

Table A.1: Allocation of countries in regions

A.2 Regional Split of Homelessness

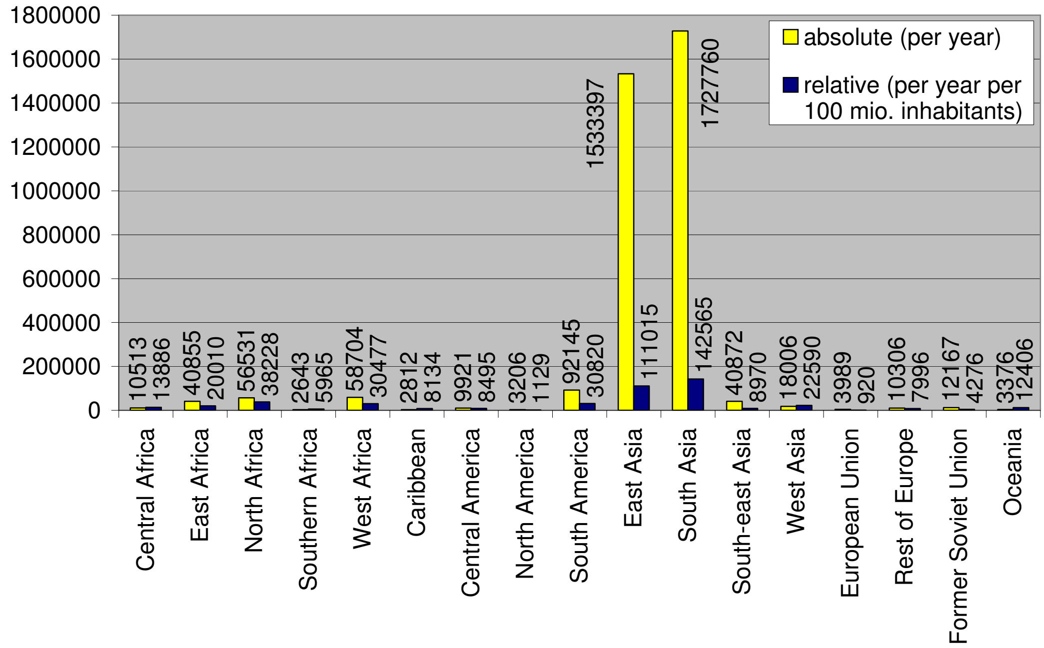


Figure A.1: Flood: regional split of homelessness

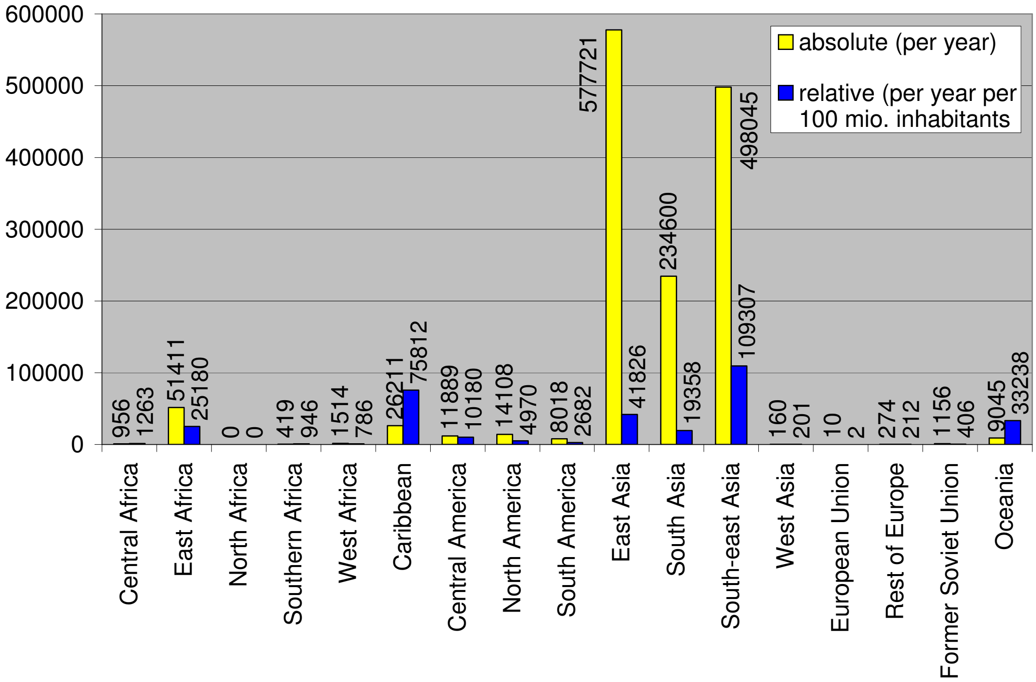


Figure A.2: Windstorm: regional split of homelessness

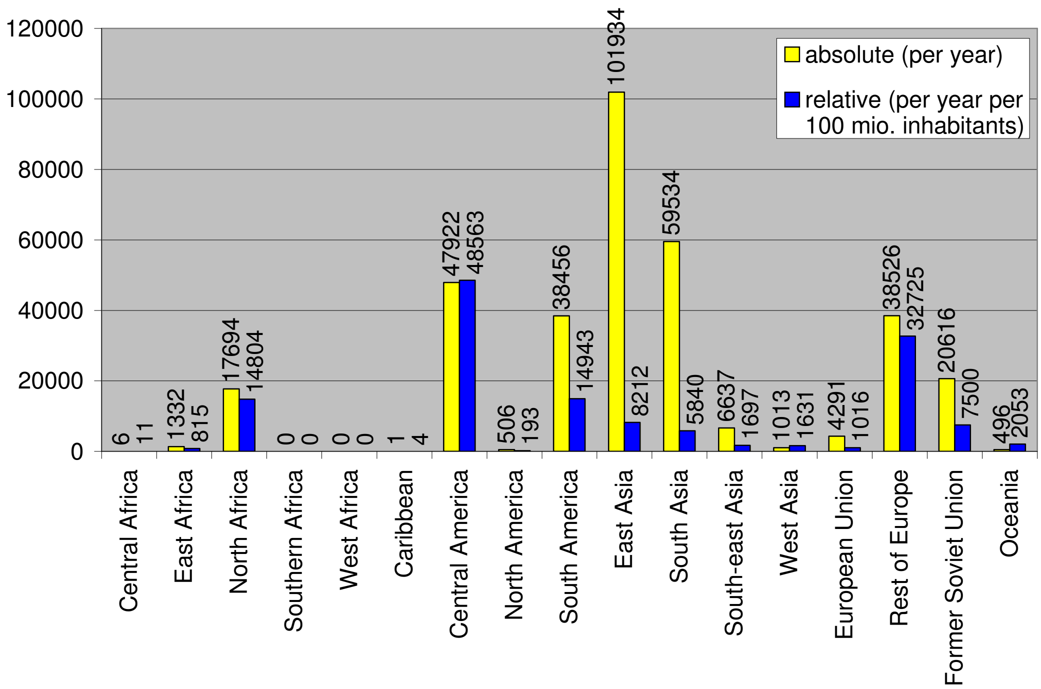


Figure A.3: Earthquake: regional split of homelessness

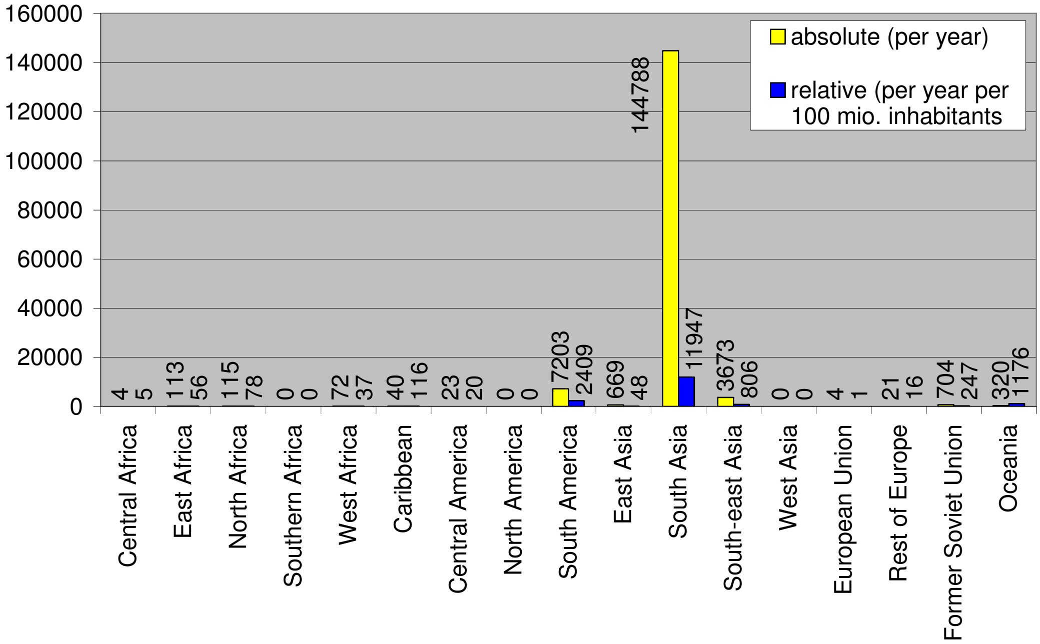


Figure A.4: Slide: regional split of homelessness

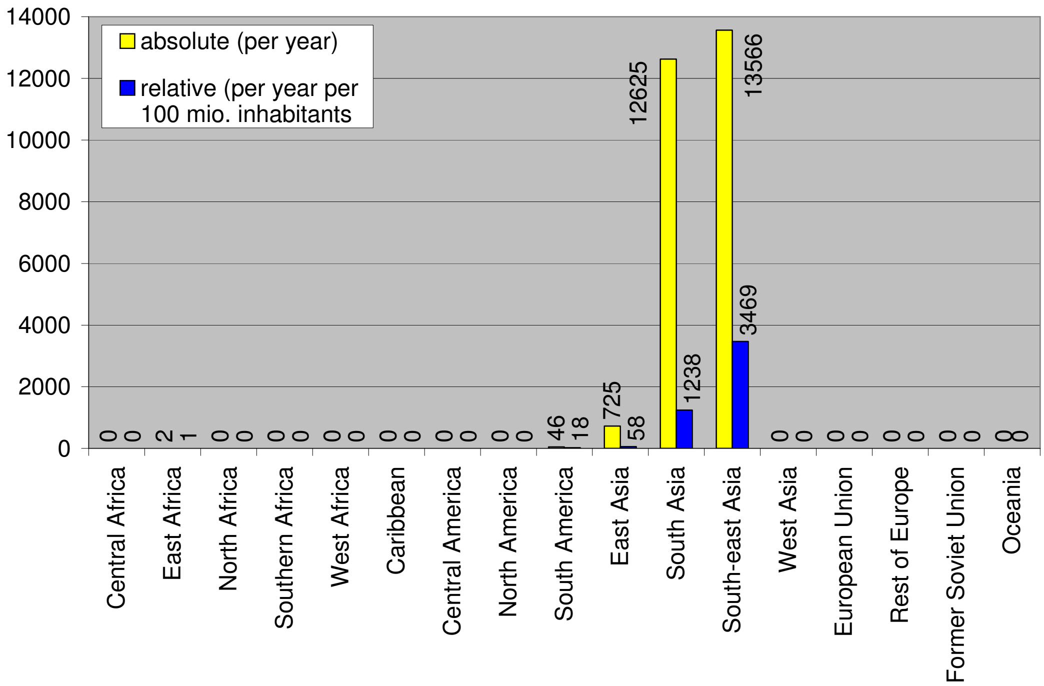


Figure A.5: Wave/surge: regional split of homelessness

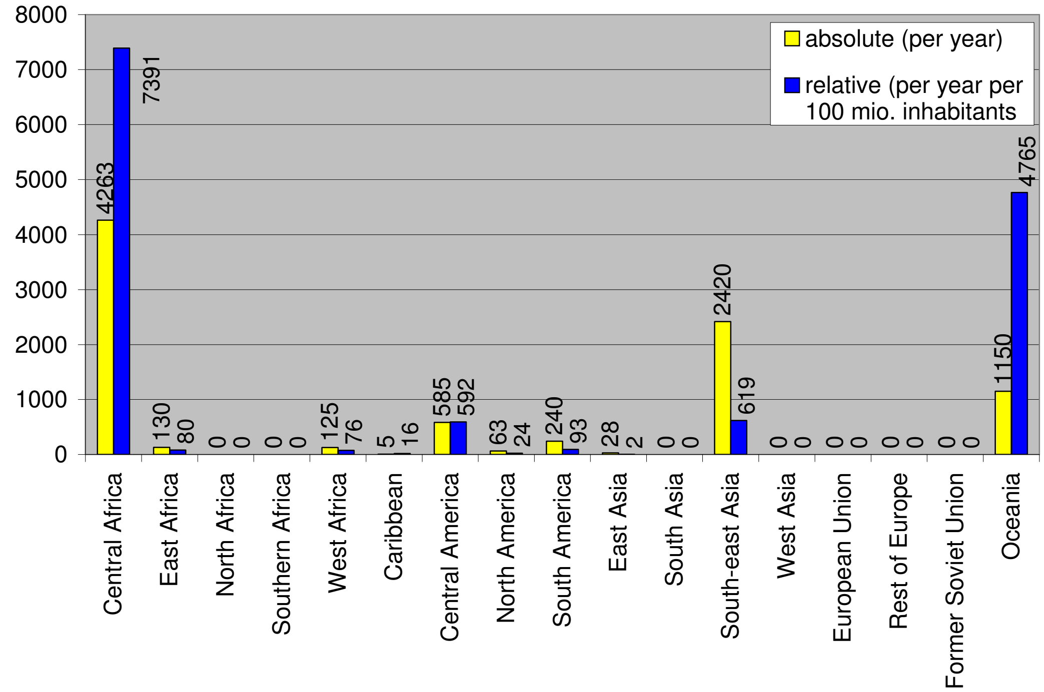


Figure A.6: Volcanic eruption: regional split of homelessness

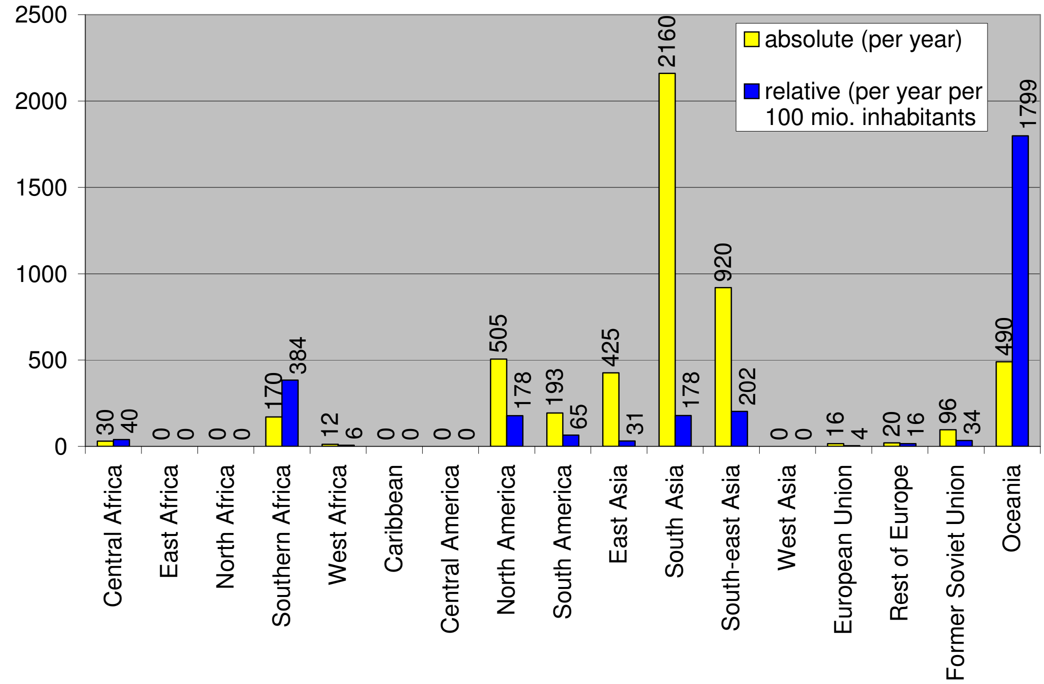


Figure A.7: Wildfire: regional split of homelessness

A.3 Risk Index for Earthquakes

RISK CLASS 0	RISK CLASS 1	RISK CLASS 2	RISK CLASS 3
Angola	Barbados	American Samoa	Algeria
Bahamas	Belgium	Belize	Australia
Benin	Botswana	Cyprus	Austria
Bermuda	Brazil	Czechoslovakia	Bolivia
Burkina Faso	Cameroon	Dominica	Lao P Dem Rep
Cambodia	Congo	Egypt	Saudi Arabia
Cape Verde Is	Gabon	France	South Africa
Cayman Islands	Ghana	Germany	Spain
Central African Rep	Grenada	Guinea	Thailand
Chad	Guyana	Hong Kong (China)	Yugoslavia
Comoros	Madagascar	Hungary	Zambia
Cook Is	Malaysia	Korea Dem P Rep	
Cote d'Ivoire	Mauritania	Korea Rep	
Denmark	Namibia	Lesotho	
Finland	New Caledonia	Libyan Arab Jamah	
French Guiana	Nigeria	Macau	
Gambia The	Norway	Marshall Is	
Guinea Bissau	Oman	Martinique	
Ireland	Paraguay	Micronesia Fed States	
Kuwait	Poland	Netherlands	
Liberia	Senegal	Niue	
Luxembourg	Sri Lanka	Samoa	
Maldives	St Vincent/Grenadines	Somalia	
Mali	Togo	St Lucia	
Mauritius	United Kingdom	Swaziland	
Niger		Switzerland	
Reunion		Vietnam	
Seychelles		Wallis and Futuna Is	
Sierra Leone		Yemen	
St Helena			
Sweden			
Turks and Caicos Is			
Tuvalu			
Uruguay			

Table A.2: Countries of risk class 0 to 3

Low HD	Medium HD		High HD
Burundi	Albania	Morocco	Argentina
Djibouti	Antigua and Barbuda	Myanmar	Bulgaria
Eritrea	Bangladesh	Nepal	Canada
Ethiopia	Bhutan	Nicaragua	Chile
Haiti	China	Pakistan	Costa Rica
Kenya	Colombia	Papua New Guinea	Cuba
Malawi	Dominican Rep.	Peru	Greece
Mozambique	Ecuador	Philippines	Iceland
Rwanda	El Salvador	Romania	Israel
Tanzania, U. Rep.	Fiji	Russian Federation	Italy
Zaire/Congo Dem Rep.	Guatemala	Solomon Islands	Japan
	Honduras	Sudan	Mexico
	India	Syrian Arab Rep.	New Zealand
	Indonesia	Tunisia	Panama
	Iran, Islamic Rep.	Turkey	Portugal
	Jamaica	Uganda	Tonga
	Jordan	Vanuatu	Trinidad and Tobago
	Lebanon	Venezuela	United States
	Mongolia	Zimbabwe	

Table A.3: Countries of risk class 4 split after HD status (based on HDI 2003)

Appendix B

The Pakistan Earthquake, 8 October 2005

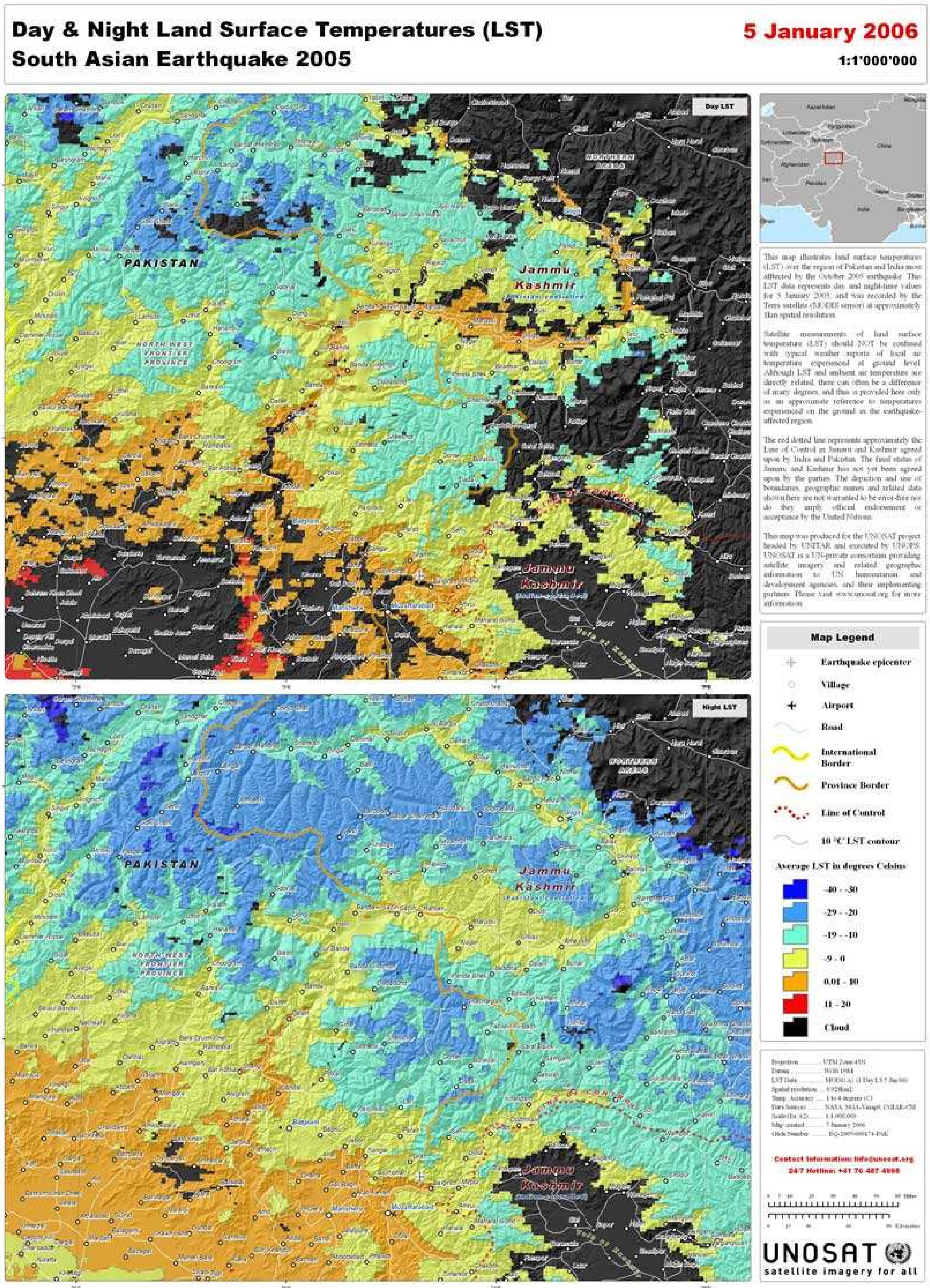


Figure B.1: Land surface temperature in disaster region, 5 Jan 2006 [UNOSAT, 2006a]

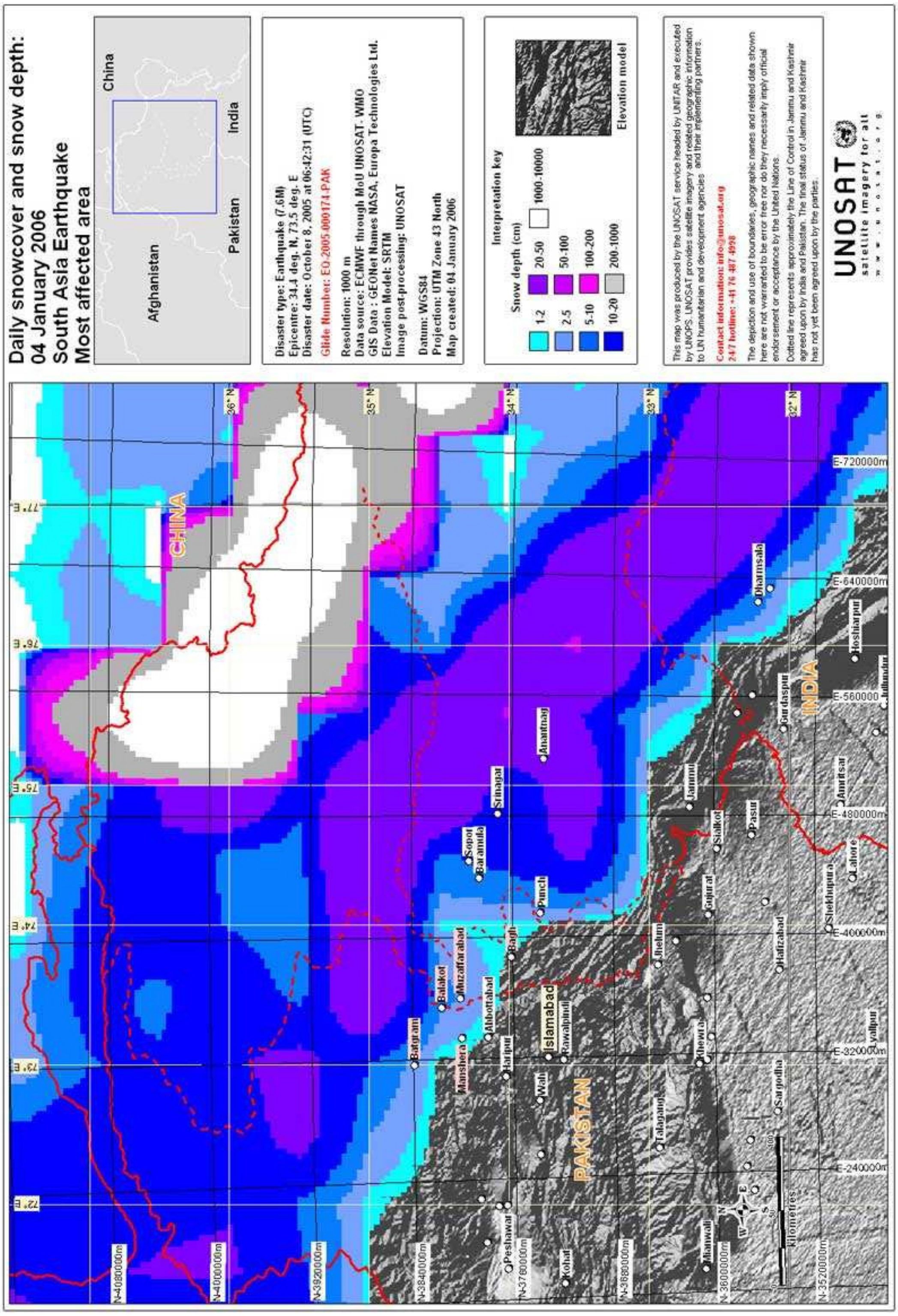


Figure B.2: Snow depth in disaster region, 4 Jan 2006 [UNOSAT, 2006b]

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